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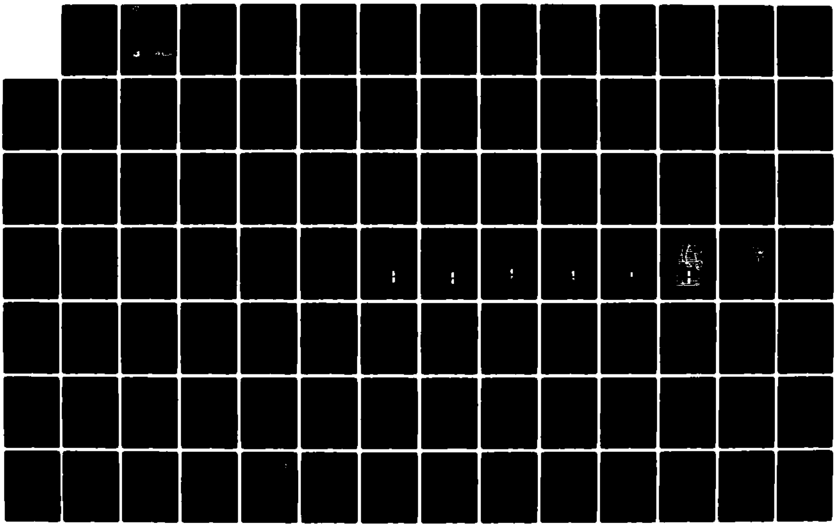

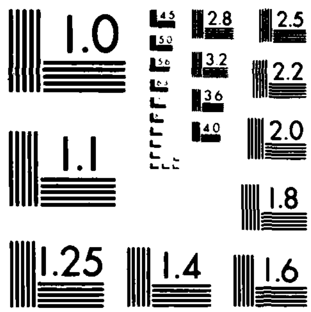

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ESL-TR-83-18

PROCEEDINGS OF THE UNITED STATES AIR FORCE AND TRI-SERVICE WIND ENERGY WORKSHOP AND CONFERENCE, 31 AUGUST - 2 SEPTEMBER 1982.

THOMAS E. KULLGREN

DEPARTMENT OF ENGINEERING MECHANICS
USAF ACADEMY
COLORADO SPRINGS, COLORADO 80840

APRIL 1983

FINAL REPORT
OCTOBER 1980 - SEPTEMBER 1982

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

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Wind Machine Applications

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report serves as the proceedings of the USAF and Tri-Service Wind Energy Workshop and Conference held at the USAF Academy, 31 August - 2 September 1982. The purpose of this activity was to transfer technology for wind site surveying and wind machine applications to the major air command and individual base levels. In addition, presentations were made by DOD organizations planning for or actually operating wind machines to foster the interchange of information.

EXECUTIVE SUMMARY

The United States Air Force and Tri-Service Wind Energy Workshop and Conference was held 31 August to 2 September 1982 at the United States Air Force Academy. This activity was attended by 37 participants from worldwide DoD organizations. Attendance was limited to DOD employees with the exception of a few selected speakers who were contractors to the government.

The goals for the conference centered around the transfer of technology on wind site surveying of DOD installations. The expected result of the conference was to educate attendees to a level allowing them to conduct their own wind program planning.

The first day was considered to be the workshop portion. An introductory slide show presented recent developments in wind machine applications. This was followed by the DOE/BPNL/SERI tape-slide show on wind site surveying. Each participant received copies of the handbook and workbook from which the tape-slide show was developed. Following this show, a sample survey of a group of Air Force installations was presented, along with a nomograph to simplify the decision-making process. The first day's program concluded with a presentation on wind instrumentation and a demonstration of a new automated data acquisition and analysis system.

The second day was the conference portion and included presentations on specialized topics and briefings on existing/planned DOD wind projects. The concluding session discussed methods of funding such projects.

The third and final day involved a tour of the Wind Energy Research Center managed by Rockwell International at Rocky Flats, Colorado. Participants received firsthand information on modern small wind machines and saw many in operation.

PREFACE

This report was prepared by the Department of Engineering Mechanics, United States Air Force Academy, Colorado Springs, CO for the Air Force Engineering and Services Center, Air Force Engineering and Services Laboratory (AFESC/RD), Tyndall AFB FL 32403, under JON 20545028.

This report documents the proceedings of the USAF and Triservice Wind Energy Workshop and Conference hosted by the Department of Engineering Mechanics, USAF Academy CO. This material is being published for the benefit of the Air Force and worldwide scientific and engineering community.

Work documented in this report was performed between October 1980 and September 1982. AFESC/RDV project officer was Lt Col Jimmy N. Fulford. Principal investigator was Lt Col Thomas E. Kullgren, USAFA.

Captains George A. Kehias, Ralph C. Rhye, and Michael S. Fitz, Robert Noun, Howard Sklar and Neil Kelley, all of the Solar Energy Research Institute, Golden, CO, were associate investigators and did much to insure the success of the conference with their expert presentations. Richard Williams of Rockwell International allowed a tour of the Wind Energy Research Center, Rocky Flats CO. Captains Mike Ritz and Ralph Rhye assisted with data reduction and analysis before the conference and handled all autovisual requirements. Captain George Kehias prepared a lucid presentation on the siting of USAF installations. Mrs. Walter Bauer typed and edited this report and handled arrangements for the conference.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication.

JIMMY N. FULFORD, Lt Col, USAF
Project Officer

FRANCIS B. CROWLEY III, Col, USAF
Director, Engineering ans Services Laboratory

MICHAEL J. RYAN, Lt Col, USAF, BSC
Chief, Environics Division

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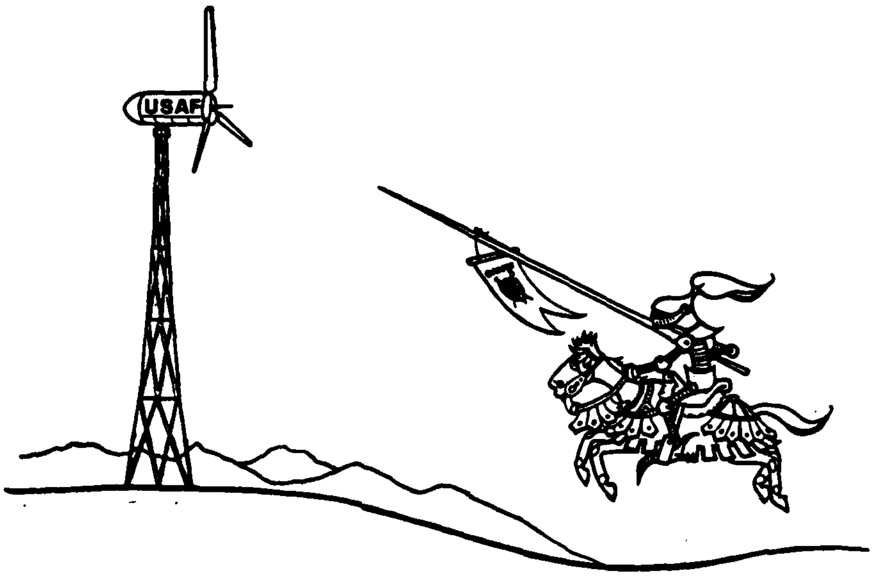
UNITED STATES AIR FORCE

AND

TRI-SERVICE

WIND ENERGY WORKSHOP AND CONFERENCE



UNITED STATES AIR FORCE ACADEMY, COLORADO

AUGUST 31 - SEPTEMBER 2, 1982

Sponsored by the
Air Force Engineering and
Services Center
Tyndall AFB, Florida

Hosted by the
Department of Engineering Mechanics
USAF Academy, Colorado

USAF AND TRI-SERVICE
WIND ENERGY WORKSHOP AND CONFERENCE
August 31-September 2, 1982

Purpose

The Workshop to be held on August 31 will deal with wind resource assessment, wind site surveying, and wind machine applications. It is designed to help MAJCOM and base-level planners make decisions regarding wind machine installations. The Conference on September 1 will deal with specific critical topics which must be answered before wind machines can be installed at DOD sites. A tour of the Rocky Flats Plant Wind Energy Research Center, Golden, Colorado, on September 2 will enable attendees to see many small wind machines operating.

Who Should Attend?

DOD energy managers and planners with an interest in wind energy but who have limited experience with wind machines are encouraged to attend the Workshop, Conference, and Rocky Flats Tour. Those with more experience may want to attend only the Conference and Tour. Priority for registration will be given to MAJCOM personnel and then to base personnel designated by the MAJCOM. Only DOD personnal are eligible to attend and registration is limited to 50 in number.

Pre-Registration

No fees are required to pre-register. No walk-in registrations will be accepted. To pre-register, fill out the attached card, check the appropriate boxes and forward not later than August 20, 1982. Cancellations after pre-registration can be made by calling Autovon 259-2531/2196 or (303) 472-2531/2196.

Fees

All fees will be collected during registration. A daily fee of $8.00 will cover all printed material, lunch and refreshments during breaks. Fees do not include housing.

Housing

Conference attendees will be housed at the Ramada Inn North. Attendees are expected to make their own reservations by writing or phoning

Ramada Inn North
4440 I-25
Colorado Springs, CO 80907
(303) 598-3951

Mention the "Wind Conference" for a special rate of $21 for a single or $28 for double occupancy.

Meals

Lunch will be at the Air Force Academy Officers' Club on August 31 and September 1. Lunch costs are included in the registration fee. Attendees are on their own for breakfast and dinner. Many excellent restaurants are within one block of the Ramada Inn North.

Transportation

If you are driving, the Ramada Inn North is at the Garden of the Gods Exit in the north part of Colorado Springs. Driving to the Conference from the Ramada Inn is discouraged due to limited parking at the Academy. If you are flying into Colorado Springs, take a taxi to the Ramada Inn North. Attendees flying into Denver will need a rental car.

Conference Chairman

Lt Colonel Thomas E. Kullgren, Professor and Acting Head of the Department of Engineering Mechanics, is chairman of the three-day Conference. Lt Colonel Kullgren has served as a contractor and consultant on wind energy matters to the Air Force Engineering and Services Center since 1977. For more details on the Conference, write or call him at

Lt Colonel Thomas E. Kullgren
Department of Engineering Mechanics (DFEM)
United States Air Force Academy
Colorado 80840

AV 259-2531/2196
(303) 472-2531/2196

SCHEDULE

WIND ENERGY WORKSHOP

Tuesday, 31 August 1982

0800	Bus Departs Ramada Inn North (with a stop at the USAF Academy Officers' Club at 0815)
0830	Registration, Fairchild Hall Lectinar Area (3rd Floor, South End)
0900-0930	Introduction and Review of the Federal Wind Program
0930-1130	DOE/BPNL/SERI Tape-Slide Show on Wind Site Surveying
1130	Bus to Officers' Club for Lunch
1300-1500	A Sample Siting Experience
1500-1600	Wind Instrumentation and Data Reduction
1615	Bus Departs for Ramada Inn North (with a stop at the Officers' Club)

SCHEDULE

WIND ENERGY CONFERENCE

Wednesday, 1 September 1982

0800	Bus Departs Ramada Inn North (with a stop at the USAF Academy Officers' Club at 0815)
0830	Current Status of the Federal Wind Program
0900	Wind Rights
0930	Third-Party Arrangements
1000	Electromagnetic Interference
1030	Remote Site Applications
1130-1300	Lunch, USAF Academy Officers' Club
1300-1430	USN, USA and USAF Reports on Wind Machine Installations
1430-1600	Funding for Wind Machines Including ECIP and Life Cycle Cost Analysis
1615	Bus Departs for Ramada Inn North (with a stop at the USAF Academy Officers' Club)

SCHEDULE

TOUR DAY

Thursday, 2 September 1982

0700	Bus Departs Ramada Inn North (with a stop at the USAF Academy Officers' Club at 0715) for a tour of the Wind Energy Research Center, Golden, Colorado
0900-1130	Tour of the Wind Energy Research Center and briefing on the Small Wind System Test Program
1130	Depart Golden for Colorado Springs
1300	Arrive at Ramada Inn North (with a stop at the USAF Academy Officers' Club)

Please tear off and mail by August 20, 1982, to:

Lt Colonel Thomas E. Kullgren
Department of Engineering Mechanics (DFEM)
United States Air Force Academy
Colorado 80840

Pre-Registration Form

Please pre-register me for the USAF and Tri-Service Wind Energy Workshop and Conference as shown below:

Name: ______________________________

Title: ______________________________

Organization: ______________________

Office Address: ____________________

____

Office Phone: AV ___________________

☐ Workshop, August 31, 1982

☐ Conference, September 1, 1982

☐ Tour, September 2, 1982

USAF AND TRI-SERVICE

WIND ENERGY WORKSHOP AND CONFERENCE

SPEAKER SCHEDULE

USN AND USAF REPORTS ON WIND MACHINE INSTALLATIONS

1300 - 1430, 1 SEPTEMBER 1982

NAME	TOPIC
JIM HELLER	U.S. NAVY WIND PROGRAM
RICHARD STEEDE	REESE AFB WIND MACHINE INSTALLATION
WAYNE BISHOP	UNIVERSITY OF DAYTON/USAF REMOTE SITE RESEARCH PROJECT
TOM HARDY	ECA WIND MACHINE INSTALLATION, BONN, GERMANY
GEORGE HOTCHCO	ASCENSION ISLAND WIND FARM

INTRODUCTORY REMARKS

LT COL THOMAS E. KULLGREN

I am pleased to welcome you to the United States Air Force and Tri-Service Wind Energy Workshop and Conference. Hopefully, this meeting will serve to transfer technology developed here at the Air Force Academy and elsewhere to the major air commands and base levels regarding wind machine applications.

Progress in wind machine development has been dramatic over the past decade and many tout this alternate energy source as the one closest to large scale commercialization. Since the Department of Defense is the largest energy consumer in the federal sector, wind machine applications may well be an economically attractive means to reduce energy costs.

At the conclusion of this conference, I hope you will have the means at your disposal to make intelligent and logical decisions as to how you might use wind machines and where to site them. Both topics can be technically complex, yet we will show you methods to reduce the complexity without losing much accuracy.

As the attached slides show, wind site surveying can pay big dividends in increased resource potential. This, coupled with favorable economics, will lead to a potentially sound wind project. A poorly sited machine in an unfavorable economic climate will likewise lead to a project failure. So time, effort, and money spent in planning a wind program will reap big dividends later and avoid embarrassing disaster.

The planning for and installation of wind machines at DoD sites is easier in some respects but more difficult in others than a similar installation in the private sector. All of these factors must be thoroughly considered when planning for wind machines.

I sincerely hope this Workshop and Conference will do much to "bring you up to speed" in the application of this promising potential alternate energy source.

USAF AND TRI-SERVICE

WIND ENERGY WORKSHOP AND CONFERENCE

31 AUGUST - 2 SEPTEMBER 1982

GOALS

1. MAJCOM: BE ABLE TO MAKE INTELLIGENT DECISIONS REGARDING WIND MACHINE APPLICATIONS IN YOUR COMMAND.

2. BASES: BE ABLE TO INTELLIGENTLY SITE A WIND MACHINE AND DETERMINE ITS ECONOMIC FEASIBILITY.

3. ALL:

   A. LEARN ABOUT CURRENT TOPICS OF MAJOR CONCERN IN THE SUCCESSFUL USE OF WIND AS AN ALTERNATE ENERGY SOURCE.

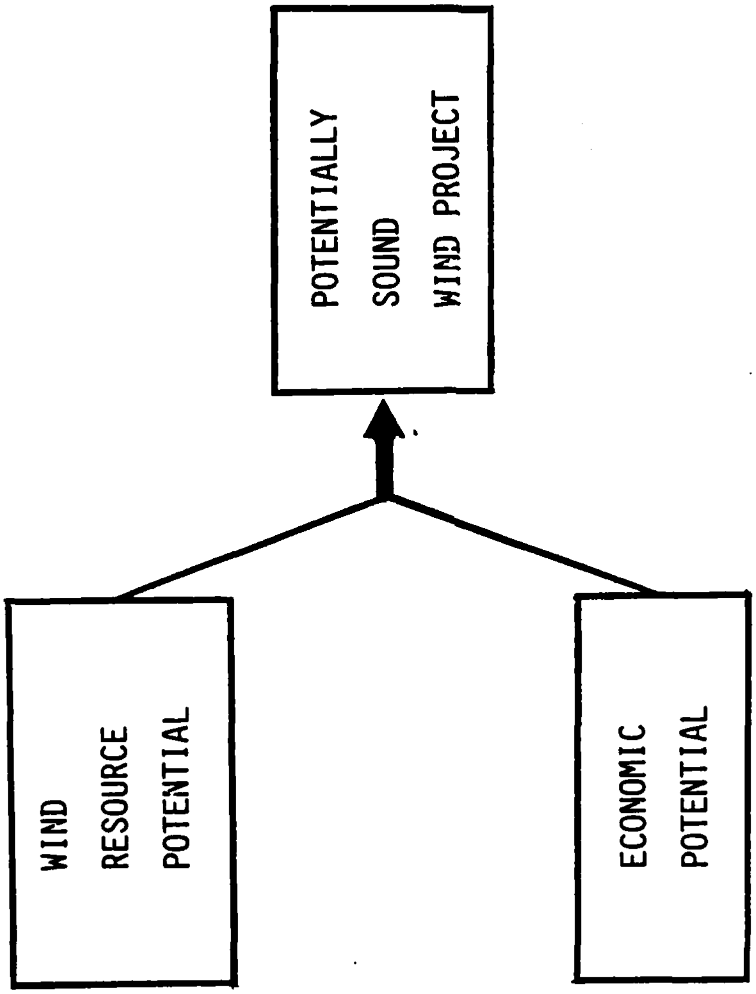
   B. UNDERSTAND THE FUNDING SOURCES AVAILABLE FOR WIND PROJECTS.

   C. LEARN ABOUT CURRENTLY AVAILABLE WIND MACHINES AND VIEW MANY UNDER TEST AT ROCKY FLATS.

WHY WIND SITE SURVEYING?

POWER IN WIND $\sim S^3$

SPEED, S (MPH)	PERCENT POWER CHANGE FROM POWER AT A BASE SPEED OF 10 MPH
5	-88
6	-78
7	-66
8	-41
9	-27
10	0
11	+33
12	+73
13	+120
14	+174
15	+238


POTENTIALLY
SOUND
WIND PROJECT
WIND
RESOURCE
POTENTIAL
ECONOMIC
POTENTIAL

DOD SITE CHARACTERISTICS

- LOW WIND SPEEDS AT SITES WITH AIRFIELDS
- RELATIVELY LOW COMMERCIAL ELECTRICAL COSTS (REMOTE SITES EXCEPTED)
- LIMITED LAND MASS AVAILABLE
- HEIGHT RESTRICTIONS
- POTENTIAL EMI PROBLEMS
- ENVIRONMENTAL PROBLEMS NOT TOO SERIOUS
- LARGE ELECTRICAL LOADS (REMOTE SITES EXCEPTED)
- REASONABLY GOOD LONG TERM WIND RECORDS

WIND DATA AVAILABILITY

CAPTAIN JAMES WOESSNER

AVAILABILITY OF WIND DATA

- MAINLY RECORDED AT AIRPORTS
- NUCLEAR AND FOSSIL POWER PLANTS
- UNIVERSITY, PRIVATE, AND GOVERNMENT RESEARCH

SLIDE 1

DISADVANTAGES OF ARCHIVED WIND DATA FOR WIND ENERGY CALCULATIONS

- OBSERVED ONLY ONCE AN HOUR
- WINDS GENERALLY MEASURED AT LOW LEVELS
- DIFFERENT ANEMOMETER PERIODS COMBINED
- AIRPORTS NORMALLY LOCATED ON FLAT TERRAIN AND NOT IN WINDY AREAS
- HORIZONTAL AND VERTICAL EXTRAPOLATION

SLIDE 2

ADVANTAGES OF ARCHIVED WIND DATA

- THE BEST DATA WE HAVE
- LONG TERM AVERAGES, EVEN RECORDED HOURLY, ARE CREDIBLE

SLIDE 3

WIND ENERGY EQUATIONS

- AVAILABLE WIND POWER (AWP)

$$AWP = \frac{1}{2n} \sum_{i=1}^{n} \rho_i \, v_i^3 = \frac{1}{2} \overline{\rho \, v^3}$$

$n \equiv$ no. of observations in averaging period

$\rho \equiv$ density of air for i th observation

$v \equiv$ wind speed of i th observation

SLIDE 3

WIND ENERGY EQUATIONS

- WIND TURBINE PERFORMANCE ($\bar{P}$)

$$\bar{P} = \text{AVERAGE POWER OUTPUT} = \sum_{v=v_1}^{v=v_2} f_i(v) \, P_i(v) \, \Delta v$$

$f(v)$ = wind speed frequency distribution

$P(v)$ = wind turbine power output function

v_1 = cut-in wind speed

v_2 = cut-out wind speed

SLIDE 5

WIND ENERGY EQUATIONS

- AVAILABLE WIND POWER (AWP)

$$AWP = \frac{1}{2} \bar{\rho} \sum_{i=1}^{c} f_i \, v_i^3$$

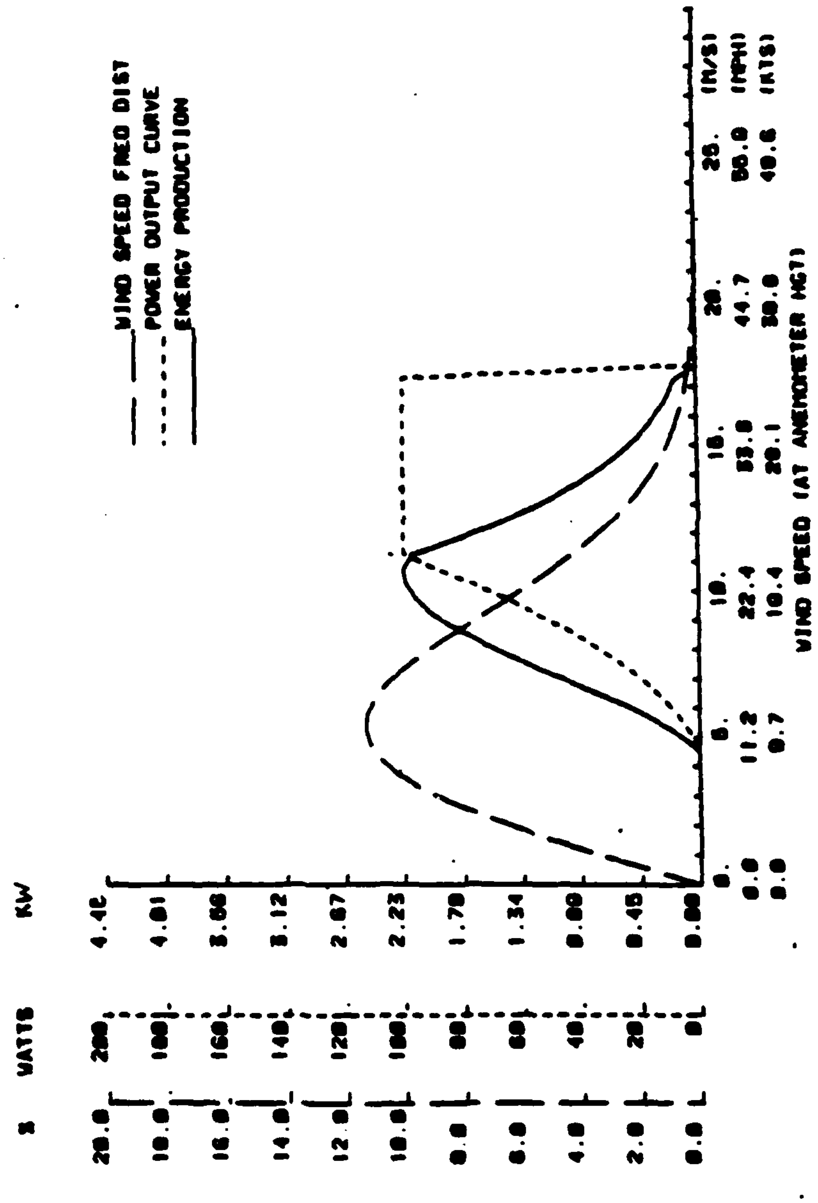
ρ = mean air density

c = the number of wind speed classes

f_i = frequency of occurrence of wind in the i th class

v_i = median wind speed of the i th class

SLIDE 4



%
WATTS
KW
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
200
180
160
140
120
100
80
60
40
20
0
4.46
4.01
3.56
3.12
2.67
2.23
1.78
1.34
0.89
0.45
0.00
WIND SPEED FREQ DIST
POWER OUTPUT CURVE
ENERGY PRODUCTION
0. 5. 10. 15. 20. 25. (M/S)
0.0 11.2 22.4 33.6 44.7 55.9 (MPH)
0.0 9.7 19.4 29.1 38.8 48.6 (KTS)
WIND SPEED (AT ANEMOMETER HGT)

MEAN ANNUAL WIND SPEED

- EASILY OBTAINABLE
- CANNOT BE USED DIRECTLY FOR CALCULATIONS
- SOURCES: FROM STAFF WEATHER OFFICER
  - -- AWS[#] CLIMATIC BRIEF
  - -- RUSSWO*
  - -- OTHER WEATHER SUMMARIES

#Air Weather Service

*Revised Uniform Summary of Surface Weather Observations

SLIDE 6

WIND SPEED DISTRIBUTIONS

- GREATER ACCURACY OF WIND ENERGY CALCULATIONS
- CURVE FITTING PROGRAM REQUIRED
- SOURCES: STAFF WEATHER OFFICER
  - --RUSSWO
  - --USAFETAC

*USAF Environmental Technical Applications Center

SLIDE 7

WIND RESOURCE ASSESSMENTS

- ESTIMATES OBTAINABLE IN DATA SPARSE AREAS
- ESTIMATES ADJUSTED TO 10M REFERENCE HEIGHT
- DIURNAL, MONTHLY, SEASONAL, ANNUAL, AND INTERANNUAL TIME SCALES
- SUBJECTIVE
- EXTRAPOLATION FORMULAS ARE NOT UNIVERSAL
- SOURCE: DOE WIND ENERGY RESOURCE ATLASES

SLIDE 8

MEASURED WINDS

- MOST ACCURATE ESTIMATE AT POINT OF INTEREST
- EXPENSIVE AND TIME CONSUMING
- CORRELATION TO LONG TERM MEAN
- REQUIRES HARDWARE, SOFTWARE, AND THE MANHOURS TO PROCESS THE DATA

SLIDE 9

A SAMPLE SITING EXPERIENCE

LT COL THOMAS E. KULLGREN
CAPT GEORGE A. KEHIAS

The purpose of this presentation is to demonstrate a sample rank-ordering of a group of Air Force bases in terms of wind resource potential and economic viability. The resource information you will see is actual data from real Air Force locations but the names have been changed. The cost of energy for each fictitious base is imaginary yet reflects current trends and is organized to make certain important points.

Slide 1 shows an alphabetical listing of bases with the source of wind data, average wind speed (mathematically calculated if not in the data base and in a variety of units) and current cost-of-energy. Fowler AFB is an imaginary remote Alaskan site and Sir Francis Drake a fictitious Pacific island.

Slides 2 through 9 show the actual data obtained for each location from different sources. An earlier speaker (Capt James Woessner, AFESC/WE) or the present authors can provide sources of data for real Air Force bases. Nevertheless, these slides cover most of the existing data formats one might find. Slides 8 and 9 represent hardcopy output from an AL-2002 data logger presently under field test at the Air Force Academy.

In Slide 10, the fictitious bases have been ranked by wind resource potential (average wind speed in mph). Yet this is certainly not the "bottom-line" since current and projected costs of energy work hand-in-hand with the resource to then predict an economically competitive wind project.

A new tool, the wind energy nomograph, was developed by one of the authors, Capt George Kehias, to assist planners in this rank-ordering procedure. This nomograph, shown in Slide 11, has near its left margin a description of how the nomograph is used. Inputs supplied by the user are:

- Ratio of the anemometer height at the location of the wind data base to the hub height of the wind machine under consideration.

- Average wind speed in mph at the anemometer height.

- The wind machine model closest to the actual power output curve of the machine being considered.

- Present costs of commercial electricity at the site in question.

- Installed cost of the wind machine (appears in the numerator of IC) and the estimated life of the machine.

- The rated power of the wind machine, P_r.

The bottom-line output from a complete cycle through the nomograph is years-to-simple-payback. Intermediate results include annual energy output and yearly savings.

Assumptions used in constructing the nomograph are the conventional ones. A Rayleigh distribution of wind speeds is assumed and the one-seventh power law is used for vertical wind speed extrapolations to hub-heights. Three forms of wind machine power output curves are assumed; all of which are in common use and match most actual machine performance curves. Economic inflation is not included in the interest of simplicity and to discourage disagreements resulting from this hard-to-project unknown.

The power of this nomograph lies not in accuracy which is admittedly limited. Rather, it permits a simple rank-ordering of a number of potential sites based upon both the wind resource and present economic picture. As with all nomographs, a side benefit is the ability to answer a variety of "what if" questions and produce a clear picture of what resource and/or economic changes would have to occur to result in a viable wind project.

Slide 12 shows the yearly savings from the nomograph while Slide 13 lists years-to-simple-payback and fictitious installed costs at each site. Use of the nomograph ends here because a more detailed life-cycle cost (LCC) analysis must now be performed to justify a project.

Slide 14 presents savings-to-investment ratios (SIR) for each of the seven locations. Differing values of O & M were assumed based upon site remoteness. The rank-ordering is the same as that from the nomograph except that Adams and Falcon have switched positions due to the indepth analysis provided by LCC. However, neither site is acceptable by either analysis method so this is a moot point.

Since this presentaion is directed at CONUS sites (remote sites are considered in a following paper), the leading CONUS base, Amrine, is chosen for further inspection. Slides 15 through 17 show hardcopy and graphical output of a Weibull fit to the actual airfield wind speed frequency distribution. This is simply a mathematical expedience for the calculations to follow. Slide 18 is output from an extrapolation of this distribution to the hub height of the wind machine under consideration. Slide 19 displays results of a linking of this wind machine to the wind resource for a period of one year.

An inspection of the available real estate on Amrine AFB can now begin. Slide 20 shows this fictitious base replete with all the standard facilities such as a runway, support buildings, a housing area and golf course. The slides to follow will depict zones within which wind machines should not be placed for reasons to be mentioned. These areas are shown hashed on the slides.

Slide 21 shows an exclusion of areas adjacent to the runway and in the runway approaches due to clear zone considerations. The circular area shown on Slide 22 is an FAA restriction based upon a structure's height and its distance from the TACAN. (Electromagnetic interference questions are considered in a following presentation.) Slide 23 represents a "judgment call" in that the high density residential and industrial areas are excluded because wind turbulence here might well reduce the power output of a wind machine. Slide 24 shows a set-back from the base boundaries for reasons of safety in case the machine

experiences a structural failure.

The sum total of all excluded areas is shown in Slide 25. The only large areas remaining are between the housing area and the highway and the housing area and the runway. For reasons of proximity to existing power distribution lines, the former area is selected for further study. Slide 26 shows a planned wind farm comprised of six wind machines at this site. Spacing of the machines is set at 10 rotor diameters to reduce the possible interference of one machine's wake on another.

The installation of such a wind farm should proceed in a phased and orderly manner. Due to uncertainties in the resource and the present lack of Air Force experience with wind machines, all of the planned six should not go in at once. Slide 27 shows a typical flow of installation. The first year is devoted to resource verification using on-site anemometry. If the resource is substantiated, the first machine is installed and if it is successful, the other five machine installations follow in quick succession. Slide 28 shows a cash flow prediction for the first five years of the project.

Assuming now that the resource has been verified, it is time to reaccomplish the LCC calculations using on-site winds and the energy output of an actual wind machine selected for installation. Slide 29 is a sample wind machine data sheet. (It is used here as a demonstration and does not represent a machine recommendation.)

Finally, Slide 30 shows the revised LCC procedure as required for Energy Conservation Investment Program funding. Here, the SIR is lower than originally predicted but it still shows some project potential. Initial planning for this project is now complete and the next step is to secure funding and actually install the wind machine.

ALPHABETICAL

BASE	DATA	$\bar{V}$	¢/KWHR
ADAMS	ETAC	6.7 KTS	15¢
AMRINE	BATTELLE	4.2 M/S	12½¢
FALCON	RUSSWO	9.0 KTS	5¢
FOWLER	REMOTE SITE BOOK	8.1 MPH	30¢
HOTNDUSTY	LETTER	8.7 KTS	10¢
SIR FRANCIS DRAKE	MAP	11.5 MPH	$1.00
SWAMP WALLER	AL-2000	15.1 MPH	2½¢

(SLIDE 1)

STATES AIR FORCE ENVIRONMENTAL TECHNICAL APPLICATIONS CENTER, SCOTT AFB, IL 6222>

ADAMS AFB, N.Y. PERIOD OF RECORD: 1963 – 75

ALL MONTHS

ANEMOMETER HEIGHT: 13 feet.

(KTS)	ND SPD(.1MPS)	NO OF OCCURENCES	PER CENT OF TOTAL	CUMMULATIVE TOT:
CALM	0	7584	10.82	10.82
1	5	814	1.16	11.98
2	10	5062	7.22	19.20
3	15	5014	7.15	26.35
4	21	7380	10.53	36.88
5	26	5947	8.48	45.36
6	31	6028	8.60	53.96
7	36	4678	6.67	60.64
8	41	6176	8.81	69.44
9	46	2922	4.17	73.61
10	51	5492	7.83	81.45
11	57	1999	2.85	84.30
12	62	3220	4.59	88.89
13	67	1300	1.85	90.75
14	72	1859	2.65	93.40
15	77	1231	1.76	95.15
16	82	951	1.36	96.51
17	87	488	0.70	97.21
18	93	554	0.79	98.00
19	98	207	0.30	98.29
20	103	546	0.78	99.07
21	108	68	0.10	99.17
22	113	209	0.30	99.47
23	118	66	0.09	99.56
24	123	111	0.16	99.72
25	129	59	0.08	99.80
26	134	65	0.09	99.90
27	139	10	0.01	99.91
28	144	32	0.05	99.96
29	149	7	0.01	99.97
30	154	19	0.03	99.99
31	159	1	0.00	99.99
32	165	3	0.00	100.00
33	170	1	0.00	100.00
34	175	0	0.0	******
35	180	0	0.0	******
36	185	0	0.0	******
37	190	0	0.0	******
38	195	0	0.0	******
39	201	0	0.0	******
40	206	0	0.0	******
41	211	0	0.0	******
42	216	0	0.0	******
43	221	0	0.0	******
44	226	0	0.0	******
45	231	0	0.0	******
	99999	0	0.0	******

(SLIDE 2)

PERCENT, FREQUENCY OF OCCURENCE, WIND SPEED VS HOUR BY MONTH

LOCATION AMRINE AFB/ CO (00005) FROM 550721 THROUGH 701231 NO OF VALID OBSERVATIONS 135044

ANEMOMETER HEIGHT 4.0 METERS REFERENCE GROUND MAST

ANNUAL

HOUR

SPEED (M/SEC)	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	ALL
CALM	21.7	20.1	21.7	22.8	22.4	23.7	23.6	20.7	18.2	15.8	13.1	11.1	9.3	8.3	8.0	7.9	8.9	10.9	13.6	15.4	17.9	20.1	21.3	21.3	16.6
1	3.8	4.0	3.6	3.8	4.1	3.9	3.7	3.7	3.1	2.8	2.6	1.9	2.0	2.0	1.8	1.5	1.8	1.9	2.8	3.3	3.0	3.8	3.9	3.7	3.0
2	16.6	17.2	17.1	15.9	16.3	16.0	15.8	15.0	14.0	12.1	11.8	10.1	8.9	9.0	9.5	9.6	9.9	11.2	12.3	16.0	16.6	16.3	16.5	17.5	13.8
3	16.6	17.0	15.7	15.8	15.6	15.2	14.3	13.8	12.4	11.5	11.3	11.5	11.5	10.5	10.3	11.4	12.9	13.5	15.6	16.4	16.9	16.9	16.7	16.4	14.2
4	12.6	11.9	11.4	11.6	11.4	10.7	11.1	11.5	11.2	11.4	10.5	11.5	11.6	12.1	11.9	12.3	12.4	14.6	14.5	14.9	12.5	12.9	12.7	11.9	12.1
5	8.3	8.6	9.6	8.9	8.6	9.0	8.9	9.3	10.4	10.7	10.8	11.1	12.3	12.0	12.8	13.0	13.5	12.6	12.9	11.1	11.4	9.4	8.8	9.0	10.5
6	5.4	6.2	6.1	5.5	5.7	5.5	5.9	6.7	7.7	7.9	8.6	8.7	9.5	9.9	9.0	9.4	10.4	10.0	9.4	6.9	6.3	5.7	5.5	5.5	7.4
7	3.9	4.1	4.0	4.3	4.2	4.3	4.7	5.1	5.4	7.1	7.2	7.9	7.2	8.1	8.7	8.3	7.7	7.3	5.9	5.0	4.2	4.2	3.6	3.9	5.7
8	3.2	3.5	3.3	3.6	3.9	3.1	3.8	4.0	5.8	6.1	6.9	7.3	8.0	7.7	7.9	8.0	7.5	6.3	4.3	3.2	3.7	3.2	4.0	3.7	5.1
9	2.4	2.4	2.4	2.3	2.5	2.8	2.4	3.4	3.2	4.5	5.1	5.7	5.9	6.5	6.5	5.9	5.4	4.0	2.8	2.4	2.1	2.2	2.0	2.0	3.6
10	2.0	1.8	1.9	1.8	1.7	1.9	2.2	2.4	3.1	3.4	4.7	5.3	5.6	5.5	5.3	5.0	3.7	2.9	2.1	1.9	2.0	1.7	1.7	1.9	3.0
11	1.0	.8	1.1	1.3	1.0	1.3	.9	1.3	1.5	1.7	2.3	2.4	2.4	2.6	2.5	2.7	2.0	1.6	1.2	1.0	1.0	1.1	.8	.8	1.5
12	.7	.8	.6	.7	.7	.9	.9	1.0	1.4	1.5	1.8	1.7	1.8	1.8	1.9	1.9	1.2	1.1	.9	.8	.7	.9	.8	.9	1.1
13	.8	.6	.5	.7	.8	.8	.7	.8	1.0	1.5	1.3	1.5	1.7	1.8	1.6	1.2	1.2	.9	.7	.7	.7	.6	.7	.6	1.0
14	.3	.3	.4	.4	.4	.4	.4	.3	.5	.6	.8	.7	.6	.7	.8	.7	.6	.4	.4	.4	.4	.4	.4	.2	.5
15	.2	.2	.3	.2	.3	.2	.4	.5	.4	.6	.7	.7	.8	.5	.7	.6	.4	.2	.3	.3	.2	.2	.1	.2	.4
16	.1	.1	.1	.1	.2	.1	.1	.2	.2	.2	.2	.4	.4	.4	.2	.2	.1	.2	.1	.1	.2	.1	.1	.1	.2
17	.1	.1	.1	.1	.1	.1	.1	.1	.2	.1	.1	.2	.2	.3	.2	.1	.1	.1	.1	.1	.1	.1	.2	.1	.1
18	.0	.0	.1	.1	.0	.1	.0	.0	.0	.0	.1	.1	.1	.1	.2	.1	.1	.0	.0	.0	.0	.1	.0	.0	.1
19	.0	.0	.1	.1	.1	.0	.1	.1	.1	.1	.1	.1	.1	.2	.1	.1	.1	.0	.0	.0	.0	.0	.0	.1	.1
20	.0	.0	.0	.0	.0	.0	.0	.0	.0	.1	.1	.0	.1	.0	.0	.1	.1	.0	.0	.0	.0	.0	.0	.1	.0
21-25	.1	.0	.1	.1	.1	.1	.1	.0	.1	.1	.1	.1	.1	.0	.1	.1	.1	.1	.1	.1	.1	.1	.1	.0	.1
26-30	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	0
31-35	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
36-40	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
41-UP	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0
TOTAL	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
AV SPD	3.4	3.5	3.5	3.5	3.5	3.5	3.5	3.8	4.2	4.6	5.0	5.3	5.5	5.6	5.6	5.5	5.1	4.7	4.2	3.8	3.7	3.5	3.4	3.4	4.2

(SLIDE 3)

DATA PROCESSING BRANCH
ETAC/USAF
AIR WEATHER SERVICE/MAC

SURFACE WINDS

PERCENTAGE FREQUENCY OF WIND DIRECTION AND SPEED (FROM HOURLY OBSERVATIONS)

13909 (STATION) — Falcon AFB, IL (STATION NAME) — [illegible] (YEARS) — ALL (MONTH)

LL WEATHER (CLASS) — ALL (HOURS (L.S.T.))

(CONDITION)

SPEED (KNTS) DIR.	1-3	4-6	7-10	11-16	17-21	22-27	28-33	34-40	41-47	48-55	≥56	%	MEAN WIND SPEED
N	.6	1.2	2.1	2.2	.9	.1	.0	.0				7.3	11.0
NNE	.5	1.0	1.9	1.6	.4	.1	.0					5.5	9.8
NE	.5	1.0	1.6	.9	.2	.0	.	.0				4.3	8.5
ENE	.5	1.0	1.4	.6	.1	.0						3.5	7.7
E	.8	1.4	1.5	.4	.0	.0	.0					4.0	6.6
ESE	.8	1.3	1.7	.5	.0	.0	.0	.0				4.5	6.9
SE	.9	2.2	3.0	1.1	.1	.0	.0	.0				7.4	7.5
SSE	.9	2.4	4.3	2.9	.6	.1	.0	.0				11.2	9.2
S	1.0	2.5	5.4	5.5	1.7	.5	.0	.0				16.6	10.9
SSW	.4	1.1	3.0	3.4	1.3	.4	.0	.0				9.6	11.0
SW	.4	.8	1.3	1.0	.3	.1	.0	.0				3.7	9.5
WSW	.3	.5	.7	.4	.1	.0	.0	.0				2.0	9.7
W	.5	.7	.7	.3	.1	.1	.0	.0	.0			2.4	7.7
WNW	.4	.6	1.8	1.4	.2	.1	.0	.0	.0			2.6	9.4
NW	.4	.6	.9	.8	.3	.1	.0	.0				3.2	10.3
NNW	.4	.8	1.6	1.7	.8	.1	.0	.0				5.4	11.6
VARBL													
CALM												6.6	
	9.1	19.4	31.6	23.7	7.1	2.1	.1	.0	.0			100.0	9.0

TOTAL NUMBER OF OBSERVATIONS 228081

(SLIDE 4)

NAME: Fowler AFB, Alaska

LATITUDE: 105° 18' W   LONGITUDE: 40°11' N

ELEVATION: 13 ft.   MISSION: Training

RESPONSIBLE COMMAND: WIND

POWER REQUIREMENTS: Constant 750 kW

CURRENT POWER SOURCE: 1-2.5kW gen.

FUEL: Artic Diesel   FUEL DELIVERY MODE: Airdrop

MONTHLY AVERAGE WIND SPEED (MPH):

J	F	M	A	M	J	J	A	S	O	N	D	YEARLY AVERAGE
9.6	9.3	9.4	7.4	5.3	6.6	9.0	8.6	7.3	7.0	7.3	10.1	8.1

Approximate
AVERAGE DAILY SOLAR RADIATION (LANGLEYS):

J	F	M	A	M	J	J	A	S	O	N	D
159	237	340	447	557	601	632	568	442	314	211	160

WEATHER DATA:

Winter:

Dry Bulb (°F) 99%	Dry Bulb (°F) 97.5%	Pvig. Wind Direc.	Mean Speed (M.P.H.)	Heating Degree Days (Annual)
43°	45°	N	15	1441

Summer:

Dry Bulb (°F) 1%	Dry Bulb (°F) 2.5%	Dry Bulb (°F) 5%	Pvig. Wind Direc.	Cooling Degree Days (Annual)
91°	88°	84%	NW	1550

ALTERNATE ENERGY SOURCES: Fair potential for geothermal space heating. Good solar potential.

(SLIDE 5)

DEPARTMENT OF THE AIR FORCE
THE DEAN OF THE FACULTY
USAF ACADEMY, COLORADO 80840

REPLY TO ATTN OF: Local Guy at Base

SUBJECT: Wind Machine Potential

TO: Head Wind Guy

In regards to your request for wind and electrical information at Hotndusty AFB, Texas, I have learned the following:

Average wind speed:	8.7 kts
Energy costs:	10¢/kWHr

When can we expect our first wind machine?

Ralph Mike Thomas

RALPH MIKE THOMAS, 2nd Lt, USAF
Office for Reply to MAJCOM

(SLIDE 6)

ANNUAL MEAN WIND SPEED

ASIA (Continued)

PNL CLASS	PERCENTAGE OF AREA IN ESTIMATED ANNUAL MEAN WIND SPEED RANGES M/SEC (MPH) 1	2	3	4	5 - 7
COUNTRY/CLIMATIC REGION	< 4.4(9.8)	4.4-5.1(11.5)	5.1-5.6(12.5)	5.6-6.0(13.4)	> 6.0(13.4)
Maldive			100		
Malaysia					
1 Western Slopes	90	10			
2 Eastern Slopes	90	10			
3 Sarawak	95	05			
4 East Coast	85	15			
5 Northwest Coast	85	15			
6 Interior Highlands	95	05			
Mongolia					
1 Altai Mountains	40	60			
2 Northern Mountains	10	30	60		
3 Plains	15	70	10	05	
Nepal*					
1 Mountains	50	50			
Oman					
1 Desert Coastal	10	75	10	05	
Pakistan					
1 Himalayas*	50	50			
2 Western Mountains	90	10			
3 Eastern Plains	80	15	05		
Philippines					
1 Northwest Slopes	80	05	05	05	05
2 Northeast Slopes	70	10	05	05	10
3 Southeast Slopes	85	15			
4 Southwest Slopes	85	15			
5 Sulj Sea Islands	90	10			
Qatar					
1 Desert Island			100		
Saudi Arabia					
1 Desert		90	10		
Singapore	100				
Sir Francis Drake		100			

*Resource in this region is considerably uncertain due to extremely mountainous terrain. The actual resource may be considerably higher than the estimate given.

(SLIDE 7)

(Swamp Waller AFB)

SERIAL NUMBER: 1

PRODUCT IS AL-2000

SOFTWARE VERSION: 0

START YEAR: 1981

START MONTH: 1

START DAY: 1

START HOUR: 00

START MINUTE: 01

DAYLIGHT SAVINGS TIME

TIME CONSTANT: 1704

END MONTH: 12

END DAY: 31

END HOUR: 23

END MINUTE: 57

NUMBER ON MONTHS STORED: 12

(SLIDE 8)

(Swamp Waller AFB)

MONTH NUMBER: 1

PEAK WIND SPEED: 61.2 MPH
DAY OF PEAK WIND SPEED: 6
HOUR OF PEAK WIND SPEED: 7
MINUTE OF PEAK WIND SPEED: 12
HOURS OF LULL: 12
DAY LULL ENDED: 21
HOUR LULL ENDED: 17
MINUTE LULL ENDED: 59

WIND SPEED DISTRIBUTION

0- 6:	126
6- 8:	65
8-10:	67
10-12:	54
12-14:	54
14-16:	52
16-18:	51
18-20:	50
20-22:	46
22-24:	34
24-26:	32
26-28:	26
28-30:	20
30-32:	15
32-34:	12
34-36:	9
36-38:	7
>38:	20

MONTH NUMBER: 2

PEAK WIND SPEED: 68.2 MPH
DAY OF PEAK WIND SPEED: 15
HOUR OF PEAK WIND SPEED: 9
MINUTE OF PEAK WIND SPEED: 17
HOURS OF LULL: 13
DAY LULL ENDED: 27
HOUR LULL ENDED: 5
MINUTE LULL ENDED: 24

WIND SPEED DISTRIBUTION

0- 6:	122
6- 8:	65
8-10:	62
10-12:	60
12-14:	58
14-16:	53
16-18:	42
18-20:	35
20-22:	35
22-24:	25
24-26:	20
26-28:	18
28-30:	11
30-32:	10
32-34:	10
34-36:	9
36-38:	8
>38:	22

(SLIDE 9)

$\bar{V}$ (MPH)

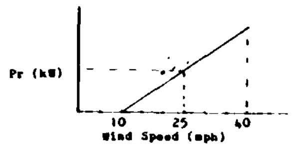
BASE	$\bar{V}$	¢/KWHR
SWAMP WALLER	15.1	2½¢
SIR FRANCIS DRAKE	11.5	$1.00
FALCON	10.4	5¢
HOTNDUSTY	10.0	10¢
AMRINE	9.4	12½¢
FOWLER	8.1	30¢
ADAMS	7.7	15¢

(SLIDE 10)

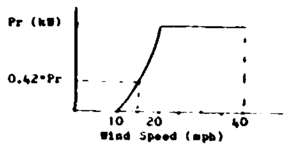
1. Average wind speed is adjusted for height using seventh power law.

2. Annual energy output is computed assuming Rayleigh distribution for wind speed and using one of three models to represent the power output of the wind machine.

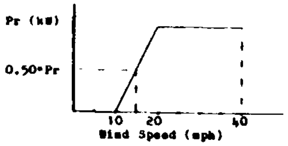
Model A:
- Operating range: 10 to 40 mph
- Output: Increases linearly over full range
- Pr: Defined as output when wind speed is 25 mph.



Model B:
- Operating range: 10 to 40 mph
- Output: Increases as a quadratic from 10 to 20
  $P(V)=(-0.375)+(6.25\times10^{-3})*V+(3.125\times10^{-3})*V^2$
  Constant output from 20 to 40 mph
- Pr: Constant output form 20 to 40 mph



Model C:
- Same as B EXCEPT
- Output: Increases linearly from 10 to 20 mph



EXAMPLE: A wind machine whose output best fits Model B is to be installed on a 30' tower. The constant output of the machine (Pr) is 20kW. The average wind speed at the site, measured with an anemometer at 10', is 12 mph. The cost of electricity is 10¢/kWHr and the machine can be installed for $60,000.

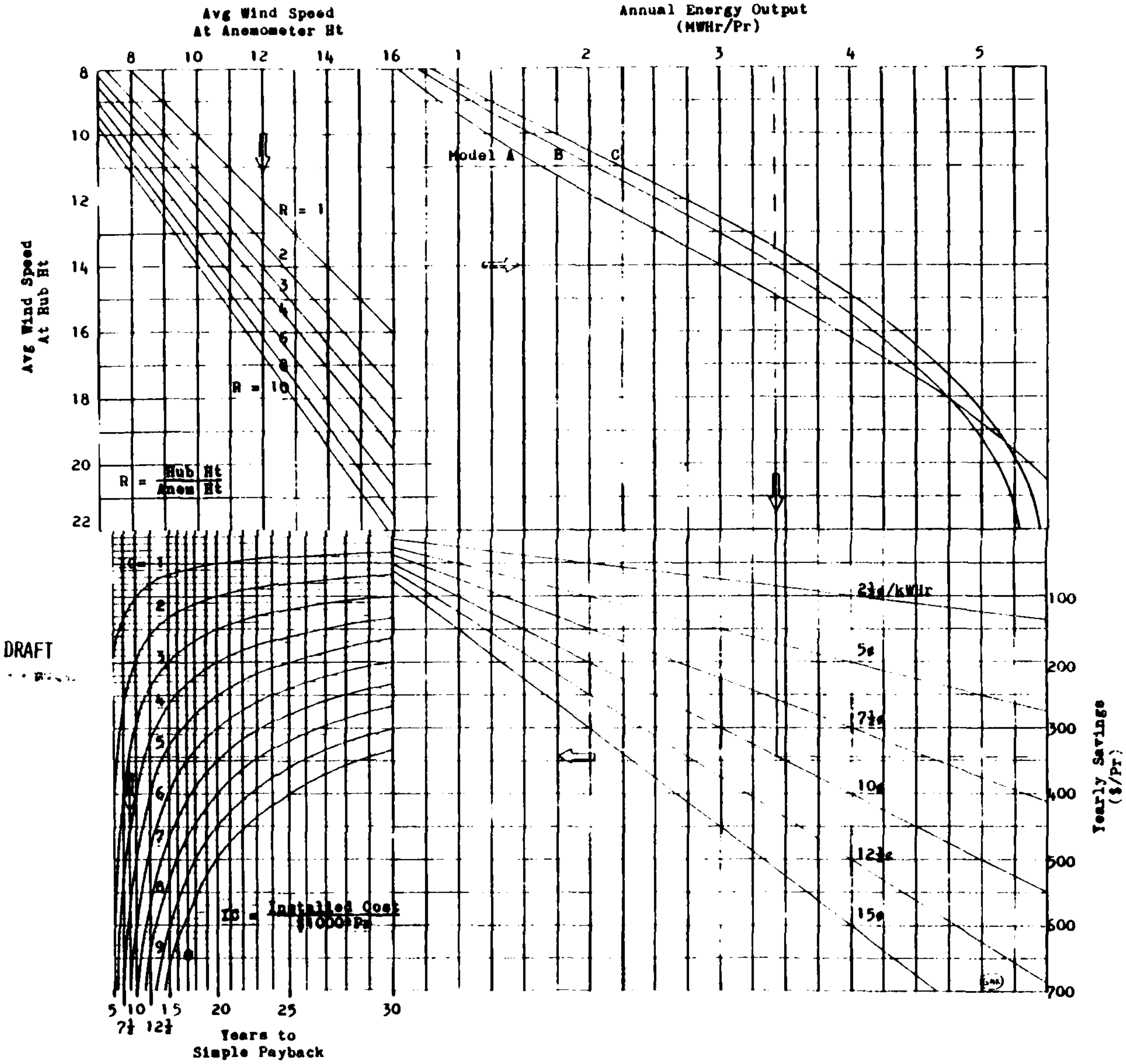
$R = \frac{30}{10} = 3$; therefore wind speed average at hub is 14.

Annual energy output = 3.4 * 20 = 68 MWHr.

Yearly savings = 345 * 20 = $6,900

$IC = \frac{\$60,000}{1000*20} = 3$; therefore it will take approximately 8.5 years to payback cost of installing the wind machine.

DRAFT



(SLIDE 11)

YEARLY SAVINGS

BASE	SAVINGS
SIR FRANCIS DRAKE	$31,800
FOWLER, AK	3,900
AMRINE, CO	2,500
HOTNDUSTY, TX	2,400
ADAMS, NY	1,637
FALCON, IL	1,300
SWAMP WALLER, FL	1,200

(SLIDE 12)

YEARS-TO-SIMPLE-PAYBACK

BASE	INSTALLED COST	Y.S.P.
SIR FRANCIS DRAKE	$180,000	5.7
AMRINE	20,000	7.9
HOTNDUSTY	30,000	12.7
FALCON	30,000	23.2
ADAMS	40,000	24.4
FOWLER	100,000	25.6
SWAMP WALLER	40,000	34.2

BESTBET WIND MACHINE

BAUER, CO

P_R = 10 KW

ANEMOMETER HEIGHT = 13 FT

HUB HEIGHT = 39 FT

(SLIDE 13)

S I R

BASE	DOE REGION	UPW*	¢/KWHR	MWHR	%O&M	I.C.	S I R
SIR FRANCIS DRAKE	9	13.40	$1.00	35.81	4	$180,000	2.44
AMRINE, CO	8	10.38	12½¢	30.52	2	20,000	1.94
HOTNDUSTY, TX	6	14.40	10¢	27.59	2	30,000	1.21
ADAMS, NY	2	12.94	15¢	18.72	2	40,000	0.75
FALCON, IL	5	14.33	5¢	30.43	2	30,000	0.55
FOWLER, AK	10	16.10	30¢	16.39	3	100,000	0.49
SWAMP WALLER, FL	4	15.23	2½¢	56.85	2	40,000	0.34

25 YEAR SYSTEM LIFE

UPW = 11.65

(SLIDE 14)

55-70
AMRINE AFB CO

BIN NO.	SPEEDS	OCCURRENCE
1	0- 0	166.0
2	0- 1	30.0
3	1- 2	138.0
4	2- 3	142.0
5	3- 4	121.0
6	4- 5	105.0
7	5- 6	74.0
8	6- 7	57.0
9	7- 8	51.0
10	8- 9	36.0
11	9- 10	30.0
12	10- 11	15.0
13	11- 12	11.0
14	12- 13	10.0
15	13- 14	5.0
16	14- 15	4.0
17	15- 16	2.0
18	16- 17	1.0
19	17- 18	1.0
20	18- 19	1.0
21	19- 20	0.0
22	20- 25	1.0

CORRELATION COEFFICIENT= .9979

SPEED	%TIME ABOVE SPEED
2	99.9
3	99.9
4	99.8
5	99.6
6	99.5
7	99.3
8	98.8
9	98.1
10	96.9
11	95.5
12	93.7
13	89.9
14	85.5
15	79.1
16	72.0
17	62.9
18	49.8
19	34.8
20	17.1
25	0.0

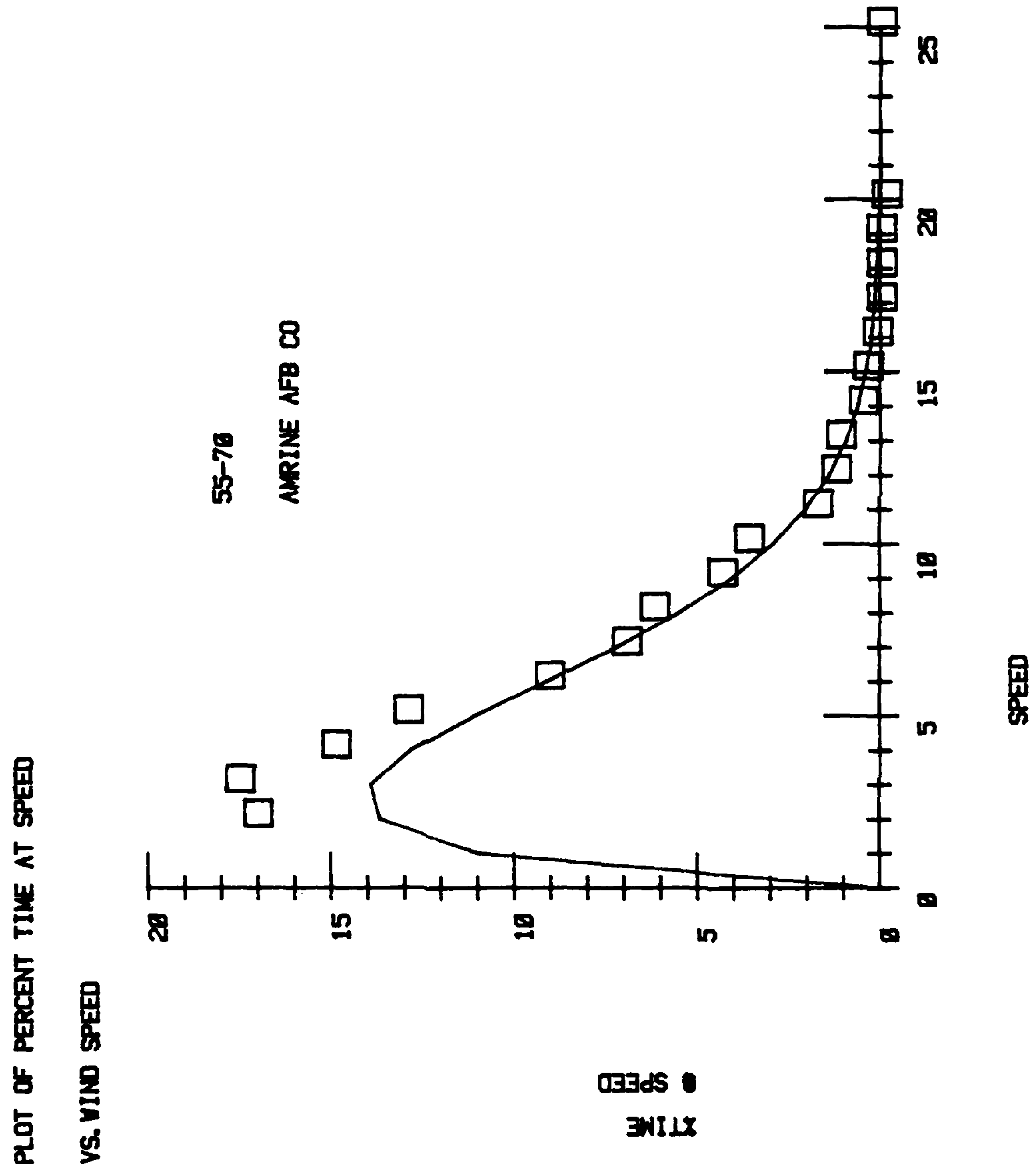
CALM IS ALL WIND SPEEDS BELOW
BIN NUMBER 3

WIND DEFINED AS CALM 29.2 % OF
THE TIME

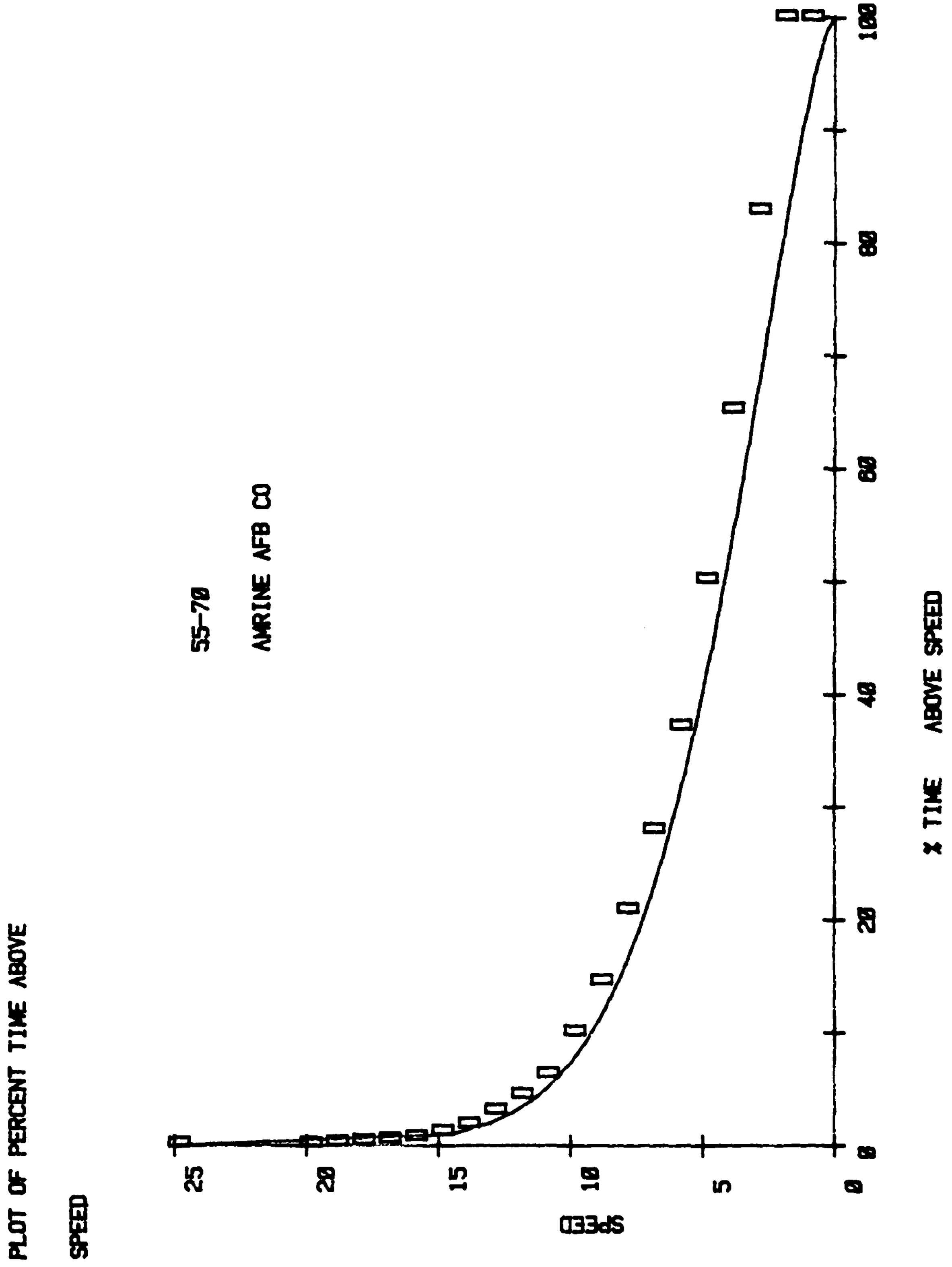
FIT IS BETWEEN BIN 3 AND BIN 22

C= 5.31 M S   K=1.52

(SLIDE 15)


PLOT OF PERCENT TIME AT SPEED
VS. WIND SPEED
55-70
AMRINE AFB CO
%TIME
@ SPEED
0
5
10
15
20
SPEED
0
5
10
15
20
25

(SLIDE 16)


PLOT OF PERCENT TIME ABOVE
SPEED
55-70
AMRINE AFB CO
SPEED
25
20
15
10
5
0
20
40
60
80
100
% TIME ABOVE SPEED

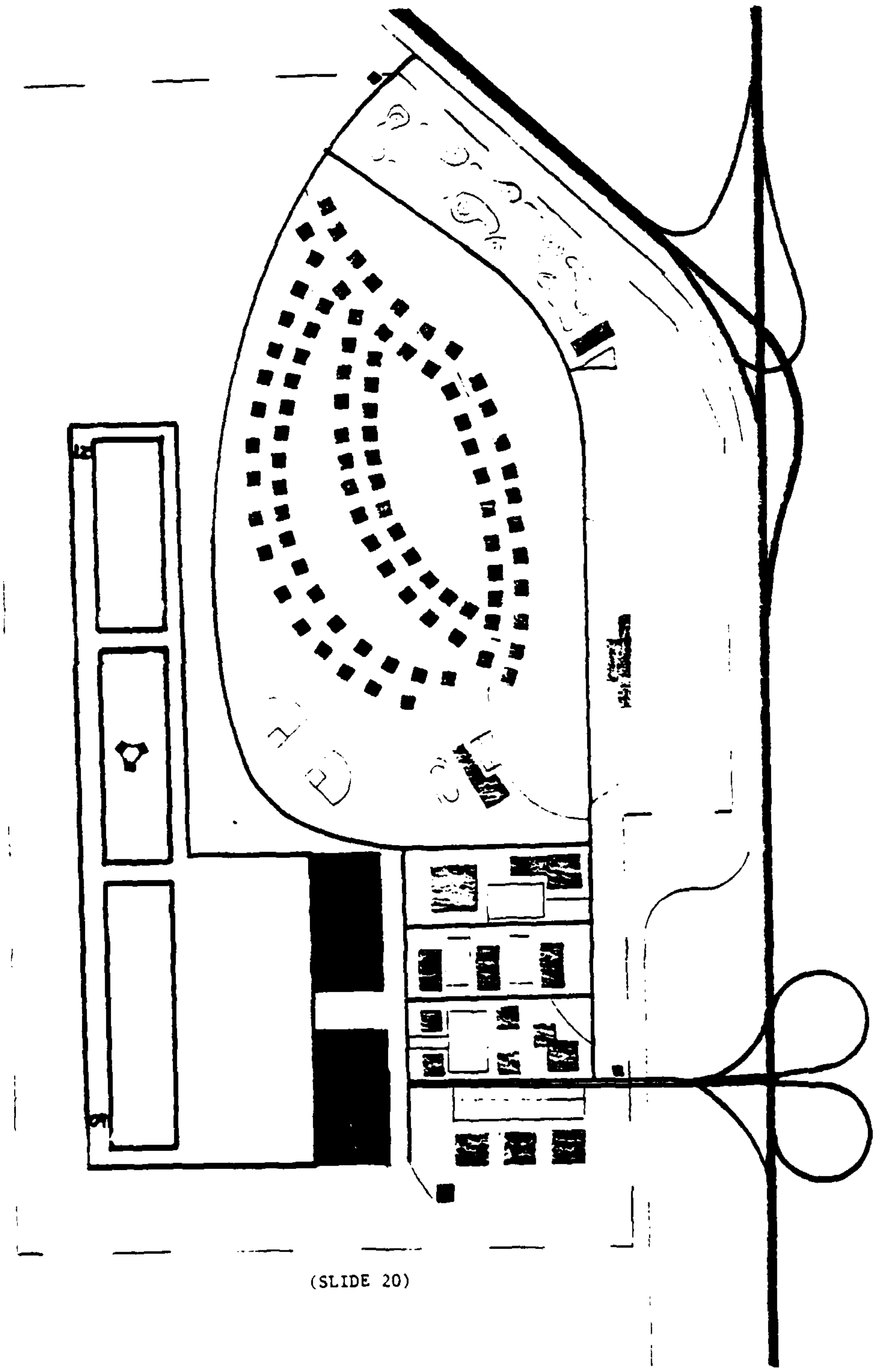
(SLIDE 17)

```
********************************
OLD HEIGHT                 13.0 FT
                            4.0 M

OLD C                     11.88 MPH
                          10.32 KTS
                           5.31 M/S

OLD K                      1.52

WEIBULL POWER         178.52 W/M^2

WEIBULL AVE WINDSPEED     10.72 MPH
                           9.31 KTS
                           4.79 M/S

********************************

STANDARD POWER LAW EXPONENT

********************************

NEW HEIGHT                 39.0 FT
                           11.9 M

NEW C                     14.90 MPH
                          12.94 KTS
                           6.66 M/S

NEW K                      1.67

WEIBULL POWER         300.18 W/M^2

WEIBULL AVE WINDSPEED     13.33 MPH
                          11.57 KTS
                           5.96 M/S

********************************
```

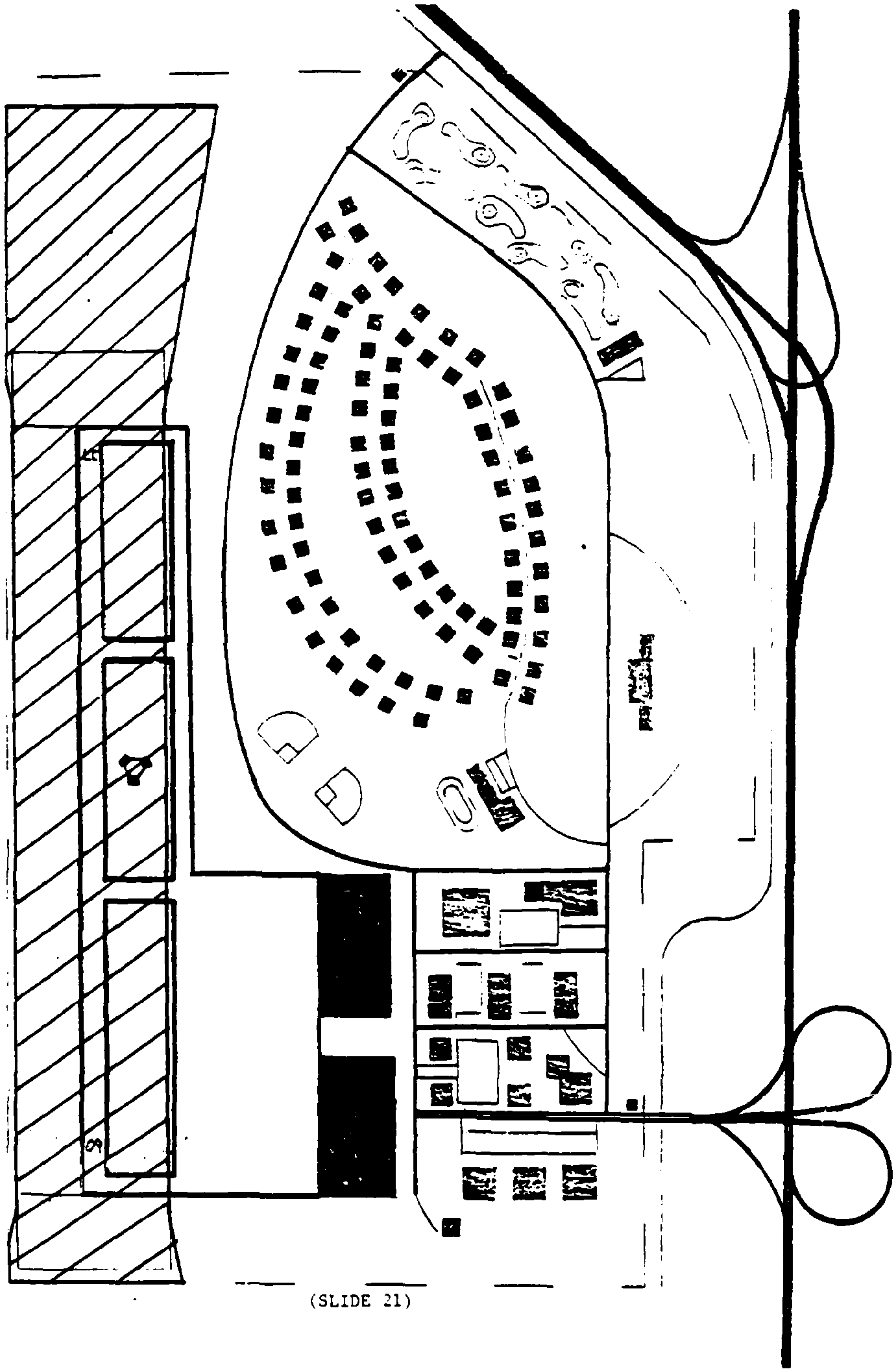
(SLIDE 18)

```
THIS DATA IS FOR A
BESTBET                   WINDMILL
SITED AT  AMRINE AFB CO


*****WINDMILL INFORMATION*****
CUT-IN VELOCITY           10.0 MPH
                           8.7 KTS
                           4.5 M/S
RATED VELOCITY            20.0 MPH
                          17.4 KTS
                           8.9 M/S
1 MPH INTERVALS             10
CUT-OUT VELOCITY          40.0 MPH
                          34.7 KTS
                          17.9 M/S
TURBINE DIAMETER          50.0 FEET
                          15.2 M
SWEPT AREA             1,963.5 SQ FT
                         182.4 SQ M
RATED POWER               10.0 KW


********SITE INFORMATION********
C                        14.90 MPH
                         12.93 KTS
                          6.66 M/S
K                             1.67
AVERAGE WINDSPEED        13.33 MPH
                         11.57 KTS
                          5.96 M/S


********POWER INFORMATION*******
OPERATING TIME          8760 HOURS
AVE POWER OUTPUT           3.48 KW
CAPACITY FACTOR               .348
ENERGY OUTPUT         30,523 KW-HR
RECOVERY FACTOR               .062
COST OF ENERGY       $ .125/KW-HR
UNIT SAVINGS          $ 20.92/M^2


******ECONOMIC INFORMATION******
PROJECT COST X .9          $ 18000
SYSTEM LIFE               25 YEARS
UPW                          11.65
UPW*                         10.38
FUTURE ENERGY SAVINGS $ 39603.84
MAINTENANCE COSTS     $   4660.00
SIR                           1.94
E/C(MBTU/K$)                 19.67
WIND ENERGY VALUE($/KWH)      .032
```

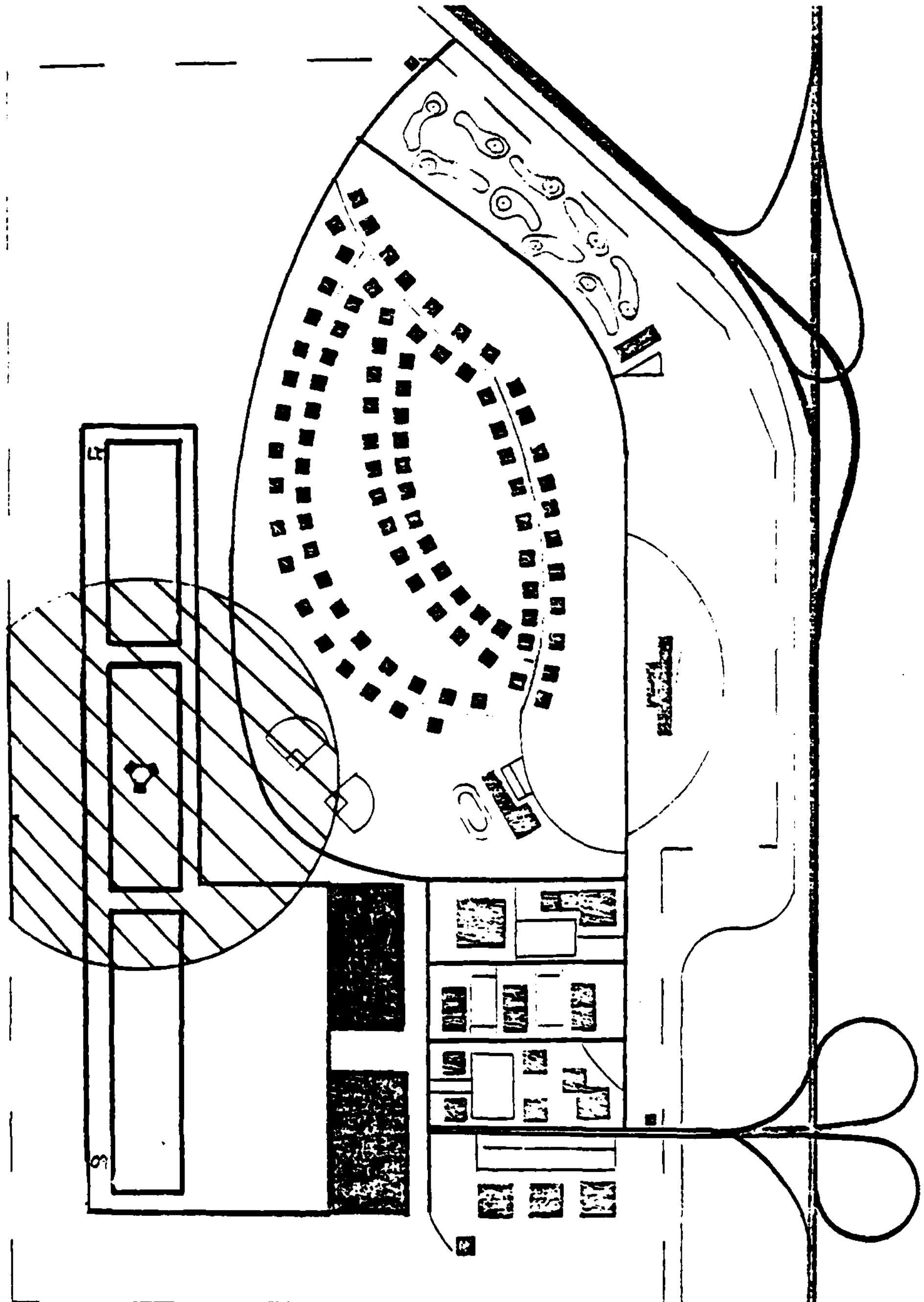
(SLIDE 19)



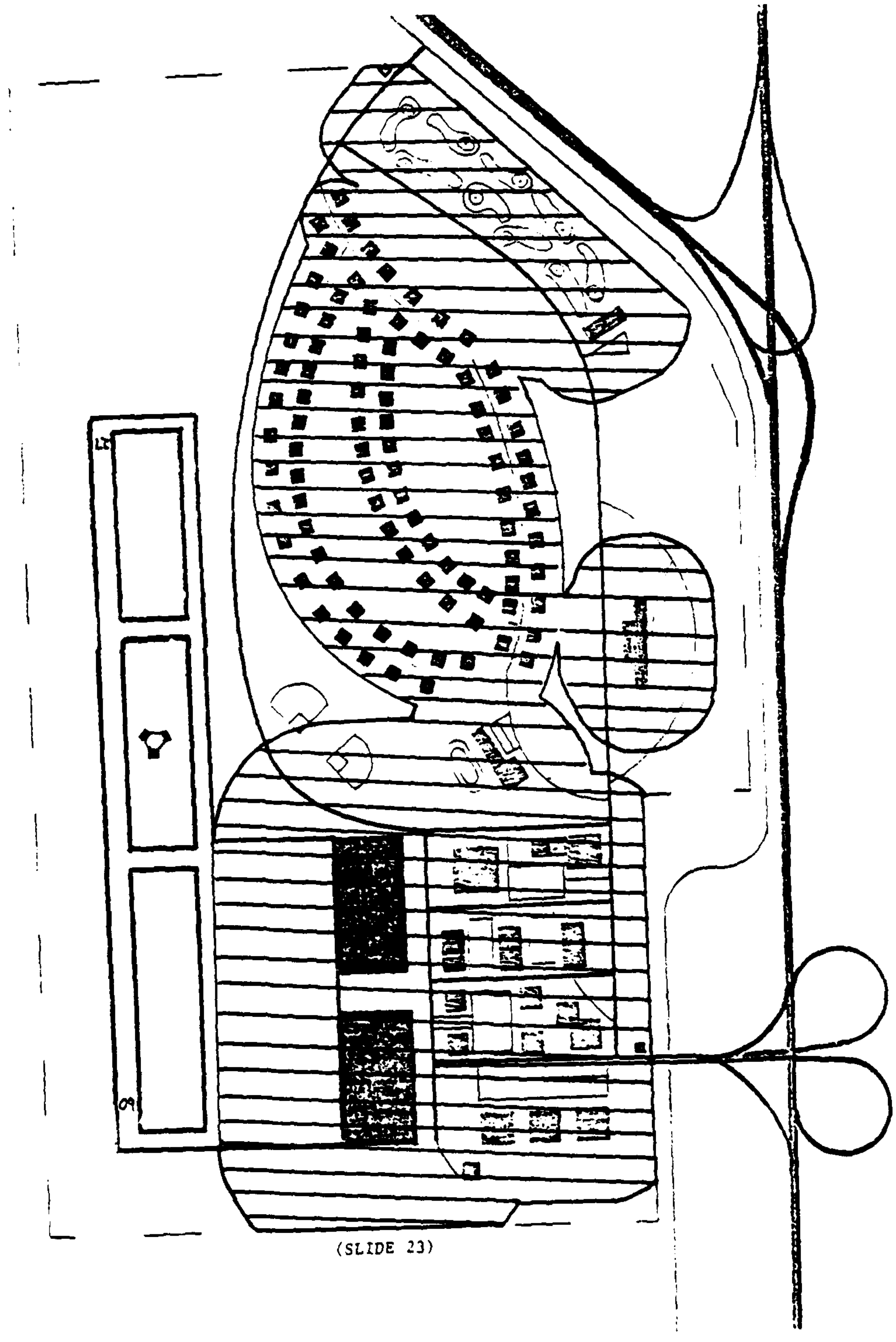
(SLIDE 20)



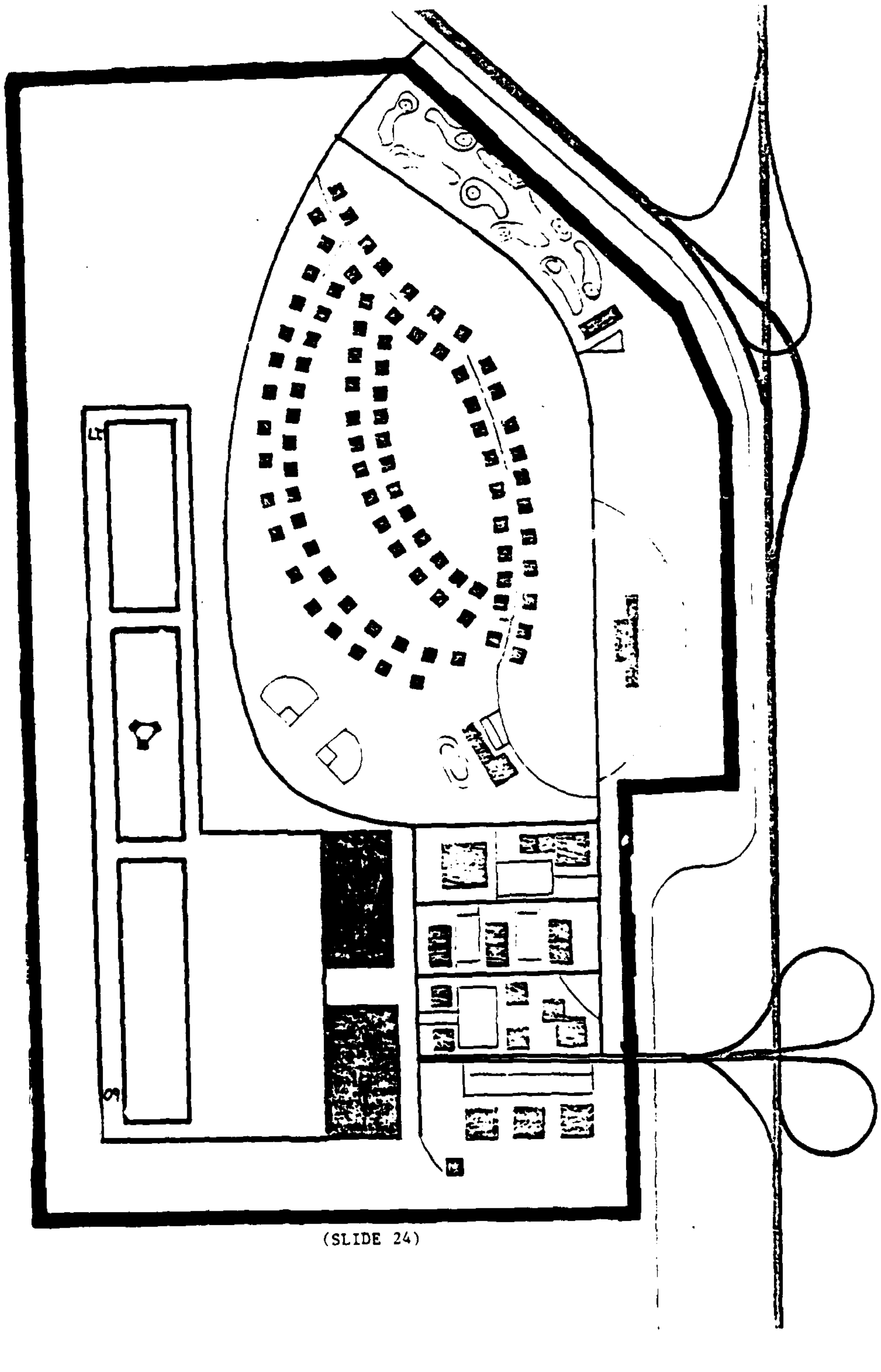
(SLIDE 21)



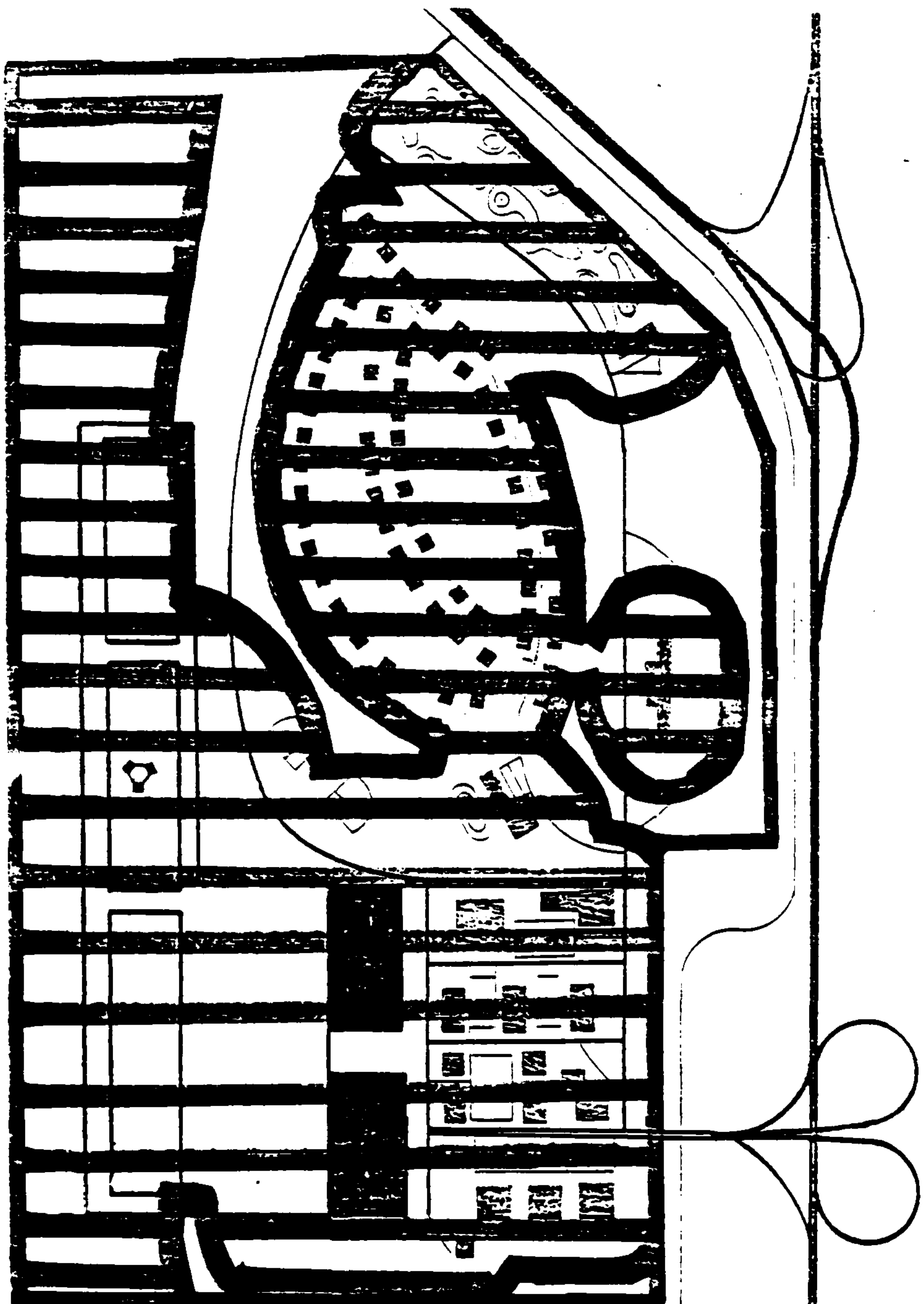
(SLIDE 22)



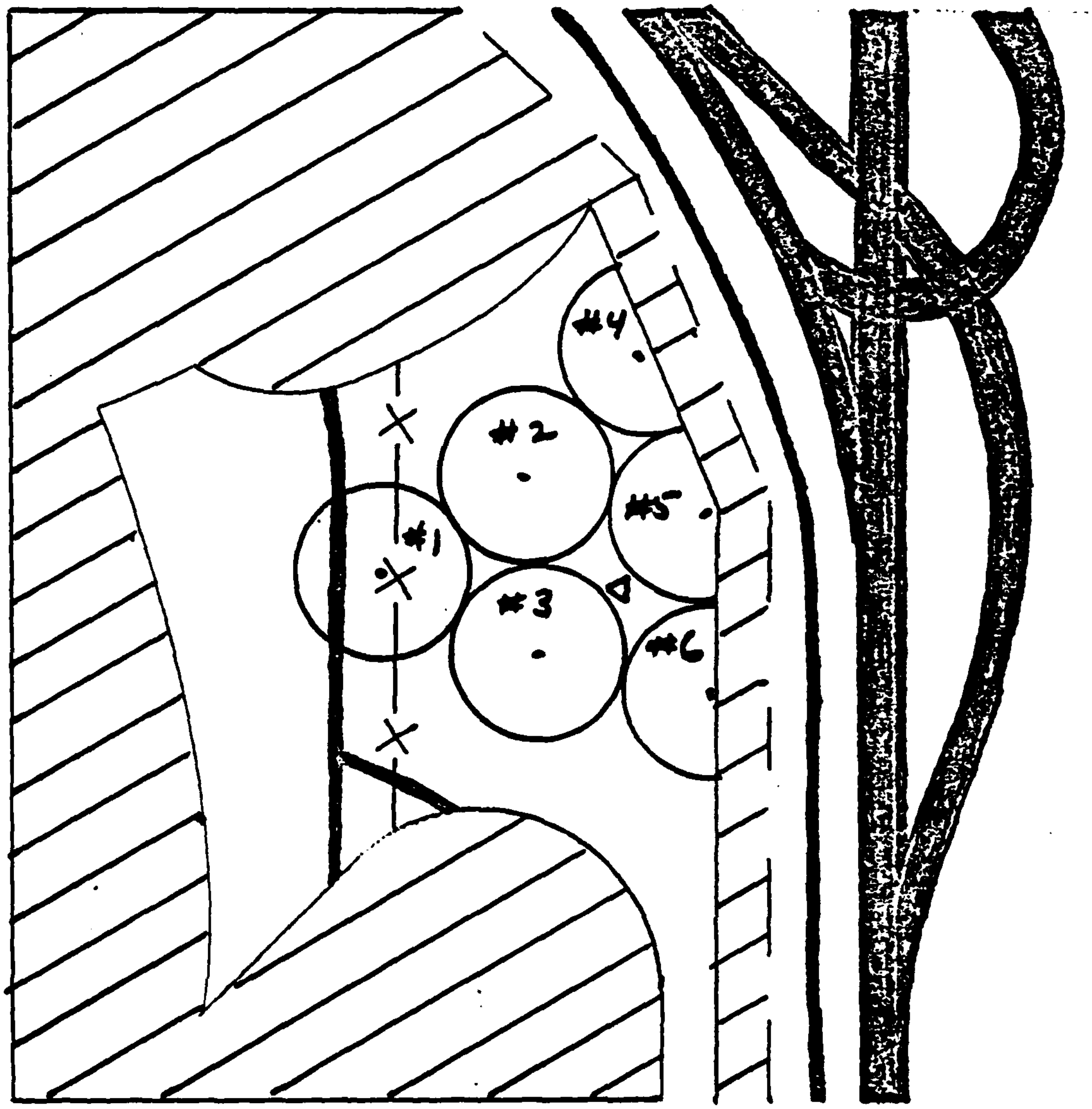
(SLIDE 23)



(SLIDE 24)



(SLIDE 25)



(SLIDE 26)

PURCHASE PLAN

YEAR 1	YEAR 2	YEAR 3	YEAR 4
INSTALL ON-SITE RECORDER ($2,000)			
START FUNDING PROCESS FOR 1ST MACHINE	INSTALL 1ST MACHINE ($20,000)		
	START FUNDING FOR MACHINES 2 AND 3	INSTALL 2 AND 3 ($40,000)	
		START FUNDING FOR MACHINES 4, 5 AND 6	INSTALL 4, 5 AND 6 ($60,000)

(SLIDE 27)

"CASH FLOW"

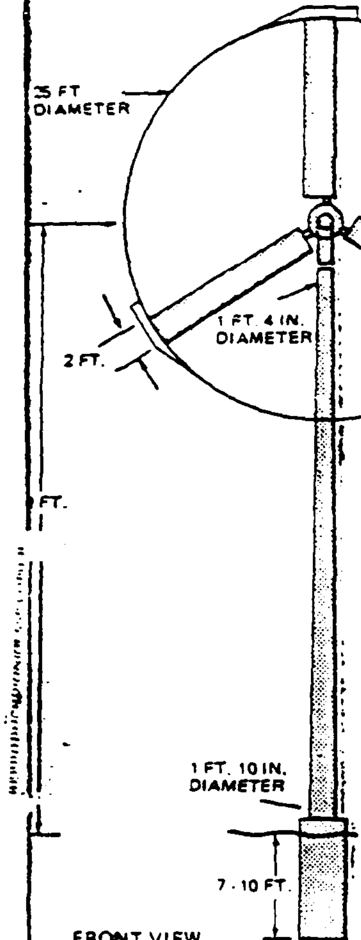
	YEAR 1	YEAR 2	YEAR 3	YEAR 4	YEAR 5
INSTALLATION	(2,000)	(20,000)	(40,000)	(60,000)	(0)
O & M		(0)	(400)	(1,200)	(2,400)
SAVINGS		1,266	5,064	11,394	15,192
TOTAL	(2,000)	(18,734)	(35,336)	(49,806)	12,792

ASSUMES FOR YEAR OF INSTALLATION

1. NO O & M
2. 1/2 FULL YEAR'S SAVINGS

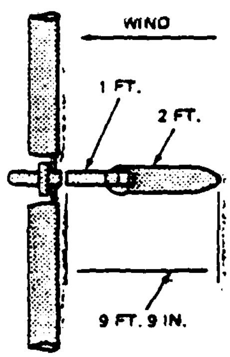
(SLIDE 28)

GRUMMAN Windstream 25

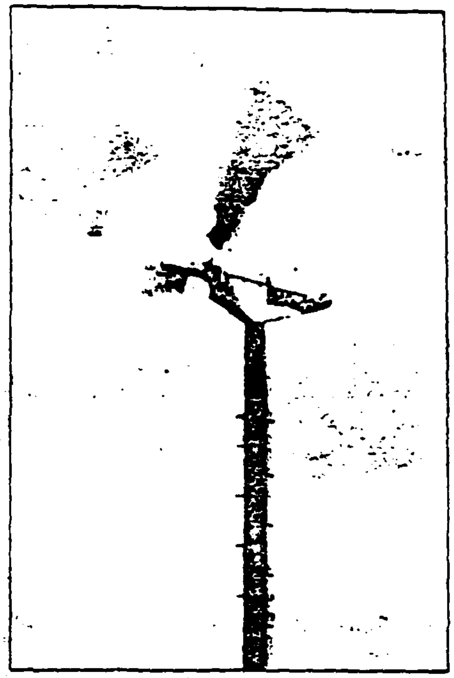


FRONT VIEW

ROTOR AIRFOIL CROSS SECTION



TOP VIEW OF UNIT

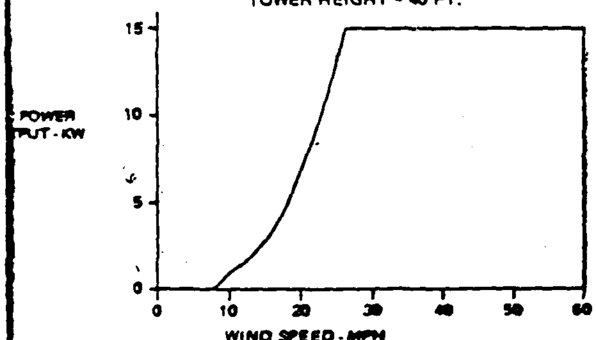


PHYSICAL DATA
ROTOR: 25 FT. DIAMETER; WEIGHT: 750 LBS.
DISC AREA: 491 SQ. FT.
DESIGN ROTOR RPM: 125
NACELLE WEIGHT: 1,250 LBS.
TOWER WEIGHT: 9,000 LBS.

Specifications subject to change without notice

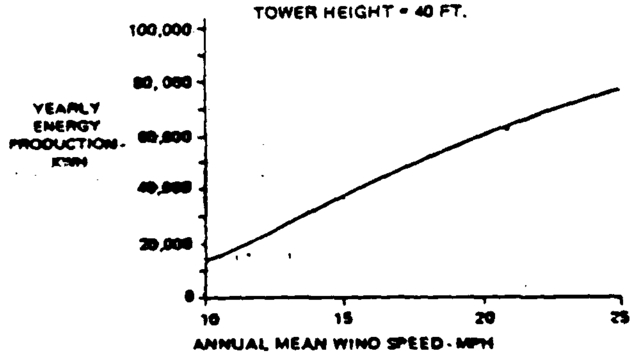
ESTIMATED POWER

TOWER HEIGHT = 40 FT.



ESTIMATED ENERGY
(Based on The British Electrical Research Assoc. statistics)

TOWER HEIGHT = 40 FT.



Further Information Contact:

GRUMMAN ENERGY SYSTEMS
4175 VETERANS MEMORIAL HIGHWAY
RONKONKOMA, NEW YORK 11779
A division of Grumman Corporation

ENERGY TECHNOLOGY YOU CAN "BANK" ON!

(SLIDE 29)

ECIP PROJECT ECONOMIC ANALYSIS

A?RINE AFB CO ,$ .13/kWHr

A. PROJECT COST			$ 30,000
1. ENERGY CONSERVATION CREDIT CALCULATION (AX0.90)			$ 27,000
B. ENERGY SAVINGS			
1. CURRENT ACTUAL UNIT COST - OIL		$/MBTU	
NATURAL GAS		$/MBTU	
ELECTRITY	10.78	$/MBTU	
COAL		$/MBTU	
2. ESTIMATED ANNUAL ENERGY SAVINGS - OIL		MBTU/YR	
NATURAL GAS		MBTU/YR	
ELECTRITY	411	MBTU/YR	
COAL		MBTU/YR	
3. UNIFORM PRESENT WORTH FACTOR,UPW* - OIL			
NATURAL GAS			
ELECTRITY	10.38		
COAL			
4. PRESENT WORTH OF ENERGY SAVINGS (B1)X(B2)X(B3)			$ 45,932
C. OTHER ASSOCIATED SAVINGS OR (COSTS)			
1. ANNUAL REOCCURRING		$(6,990)	
2. INDIVIDUAL		$	
3. TOTAL ADDITIONAL SAVINGS OR (COSTS)			$(6,990)
D. NET PRESENT WORTH OF SAVINGS (B4)+(C3)			$ 38,942
E. SAVINGS INVESTMENT RATIO (D)/(A1)			SIR = 1.44
F. ENERGY TO COST RATIO (MBTU/$1,000) (B2)/(A)			E/C = 13.7

(SLIDE 30)

WIND INSTRUMENTATION AND DATA REDUCTION

CAPTAIN MICHAEL S. FITZ
CAPTAIN RALPH C. RHYE

For the past year, personnel of the USAF Academy (USAFA) wind research project have been testing the AL-2002 wind data logger developed and marketed by Second Wind, Inc., of Cambridge, Massachusetts. A 30 meter tubular truss tower was erected near the northern boundary of the 18,000 acre USAF installation. This tower was equipped with four levels of instrumentation and two recorders. The AL-2002 is a "smart" recorder in which data is temporarily stored, managed, reduced and then read to an EPROM resident in the recorder. To analyze the data on the EPROM in an automatic mode (it can also be accessed at the recorder itself), the EPROM is removed and read using an EPROM reader connected to a desktop computer. However, software is necessary to accomplish this task and to produce output in a useable format. This software has been completed and is presently in use. The remainder of this presentation will cover the installation, data management and data reduction of information from the AL-2002.

Slide 1 shows a suggested typical AL-2002 wind vane and anemometer installation. The recorder itself is attached near the base of the tower at eye level. Two levels of recording are standard and more installation particulars are contained in the equipment manual. Slide 2 schematically depicts the AL-2002 input and output. Gustiness or turbulence in yaw is recorded as hours in a wind speed bin in three categories of angular acceleration. This is graphically shown in Slide 3 and is described in more detail in the operating manual.

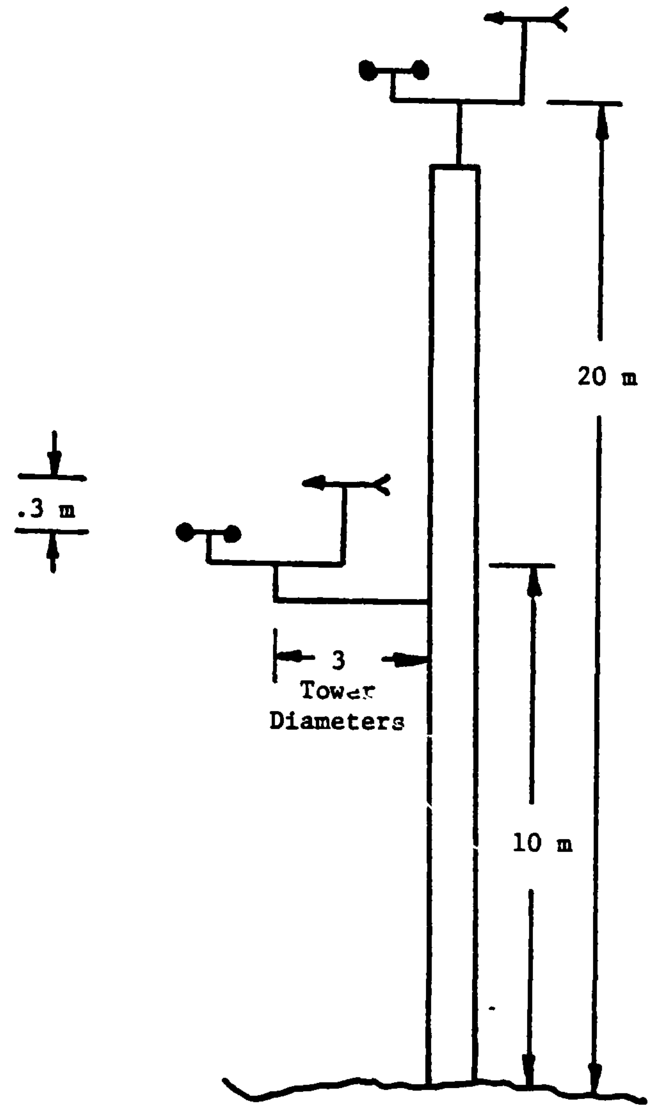
Slide 4 shows a typical wind speed frequency distribution automatically produced by the computer software as an EPROM is read. Numbers at the top of each bar on the graph represent hours at the average speed of that bin. Similarly, Slide 5 is a wind rose showing hours in four speed groups for eight points of the compass. Slides 6-9 are individual wind roses for each of the wind speed groups shown together in Slide 5.

The diurnal variation of wind speed is shown in Slide 10 along with the standard deviation about an average speed for each two-hour period in a month. Slides 11 and 12 show automatically produced hardcopy of the same information shown graphically in Slides 4 to 10. The data shown in the entire group of Slides 4 to 12 represent the standard output from a monthly record read from an AL-2002 EPROM.

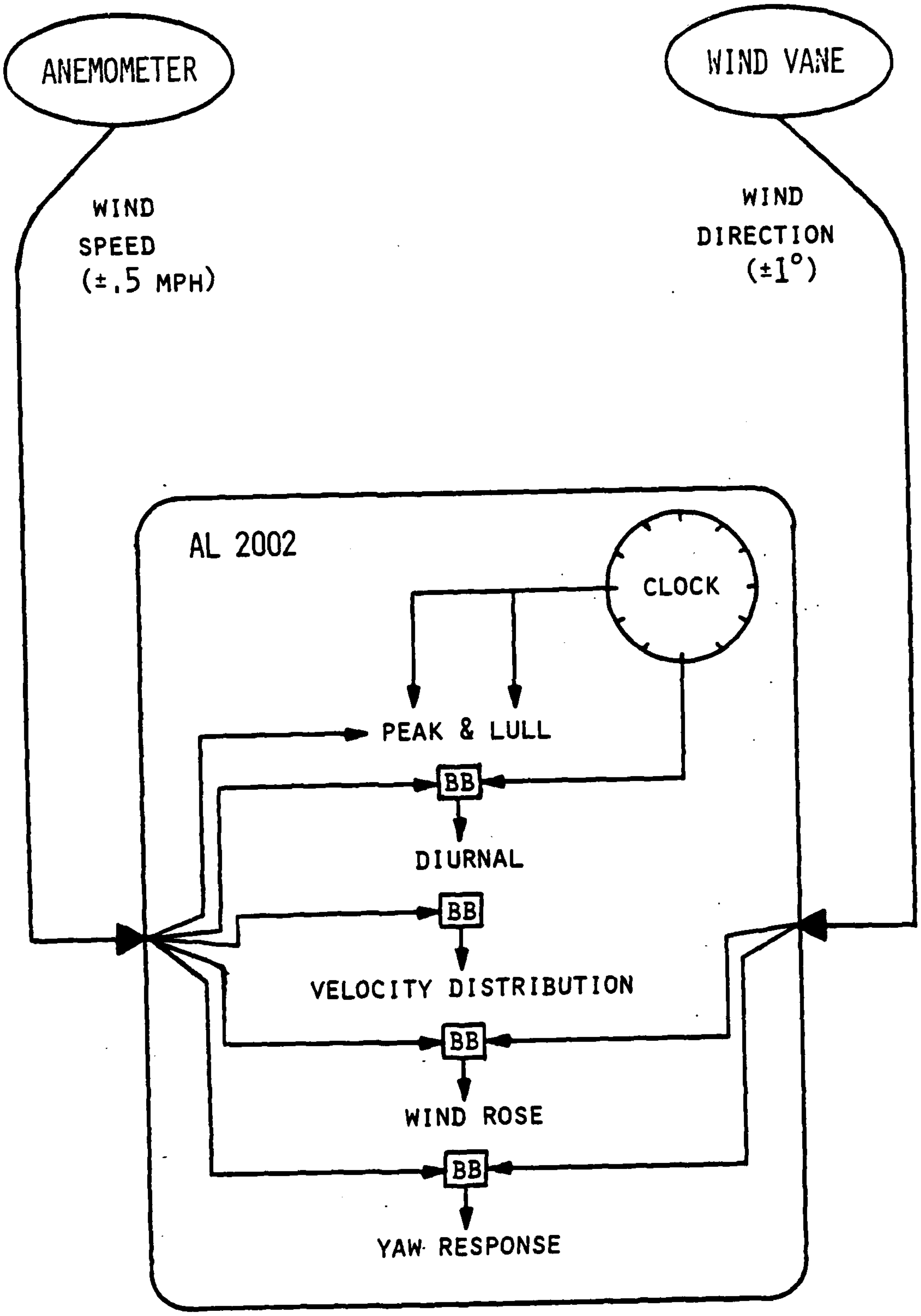
This method of recording and data reduction is extremely simple and lends itself well for use at other Air Force installations. The service of reading EPROMs from locations other than USAFA is being provided on request by the Academy research team.

RECOMMENDED WIND MEASUREMENT TOWER

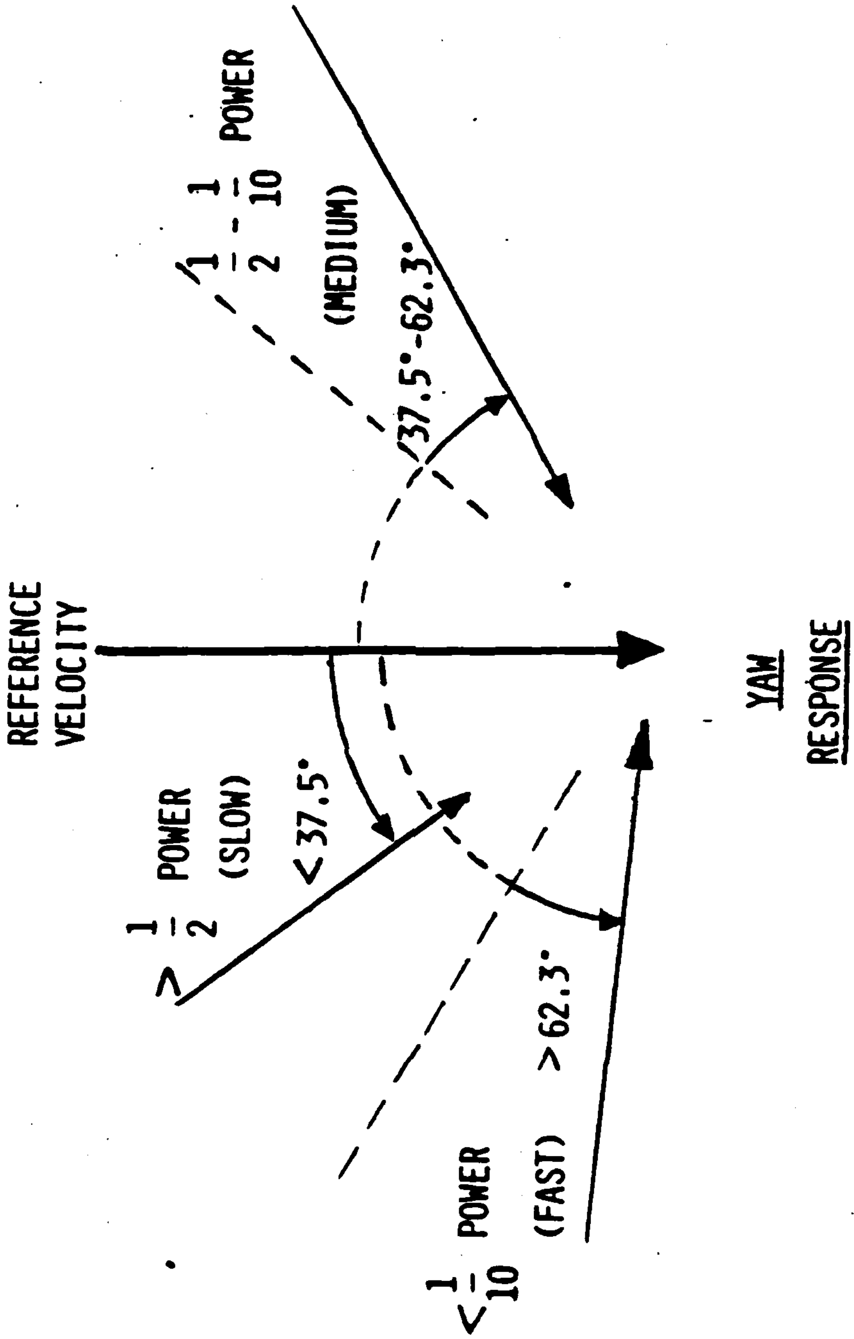
(AL-2002)



(SLIDE 1)

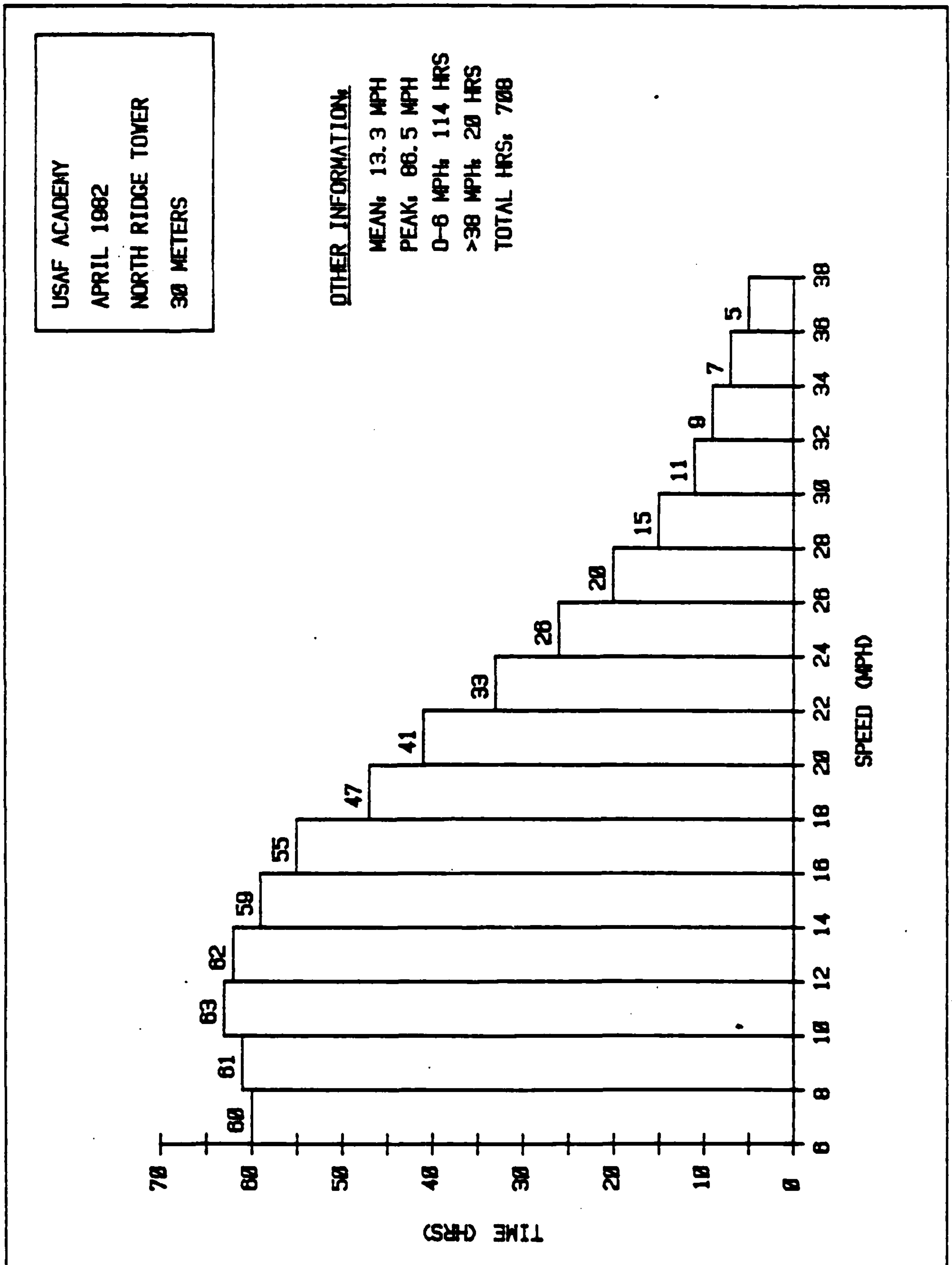

ANEMOMETER
WIND VANE
WIND
SPEED
(±.5 MPH)
WIND
DIRECTION
(±1°)
AL 2002
CLOCK
PEAK & LULL
BB
DIURNAL
BB
VELOCITY DISTRIBUTION
BB
WIND ROSE
BB
YAW RESPONSE

(SLIDE 2)



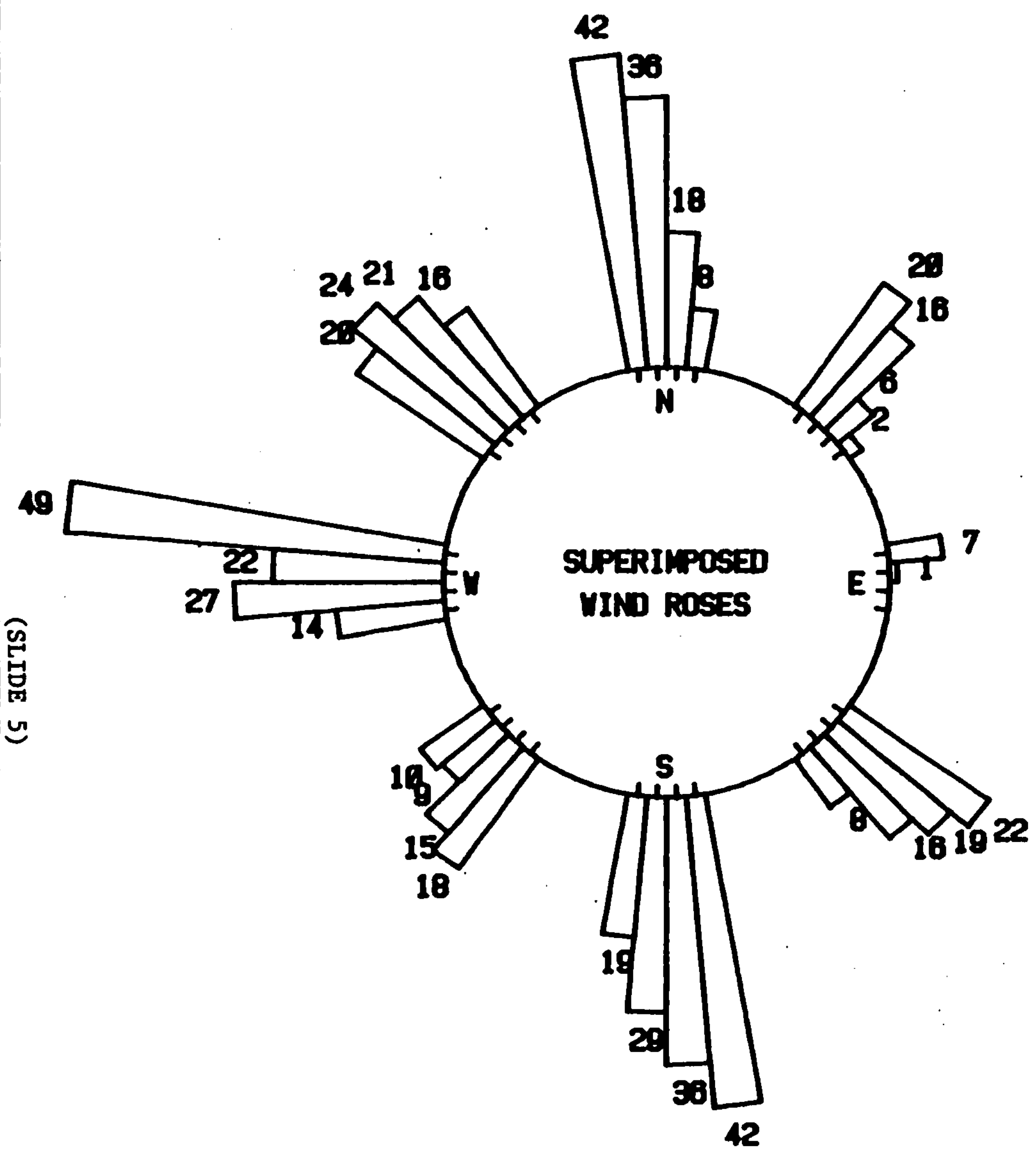
REFERENCE VELOCITY
YAW RESPONSE
> 1/2 POWER
(SLOW)
< 37.5°
1/2 - 1/10 POWER
(MEDIUM)
37.5°-62.3°
< 1/10 POWER
(FAST)
> 62.3°

(SLIDE 3)

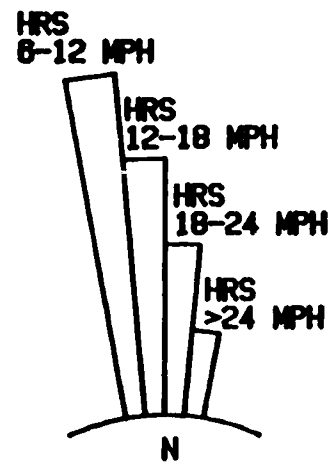

USAF ACADEMY
APRIL 1982
NORTH RIDGE TOWER
30 METERS
OTHER INFORMATION:
MEAN: 13.3 MPH
PEAK: 66.5 MPH
0-6 MPH: 114 HRS
>38 MPH: 20 HRS
TOTAL HRS: 708
TIME (HRS)
SPEED (MPH)
0
10
20
30
40
50
60
70
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
60
61
63
62
59
55
47
41
33
26
20
15
11
9
7
5

(SLIDE 4)

USAF ACADEMY
APRIL 1982
NORTH RIDGE TOWER
30 METERS



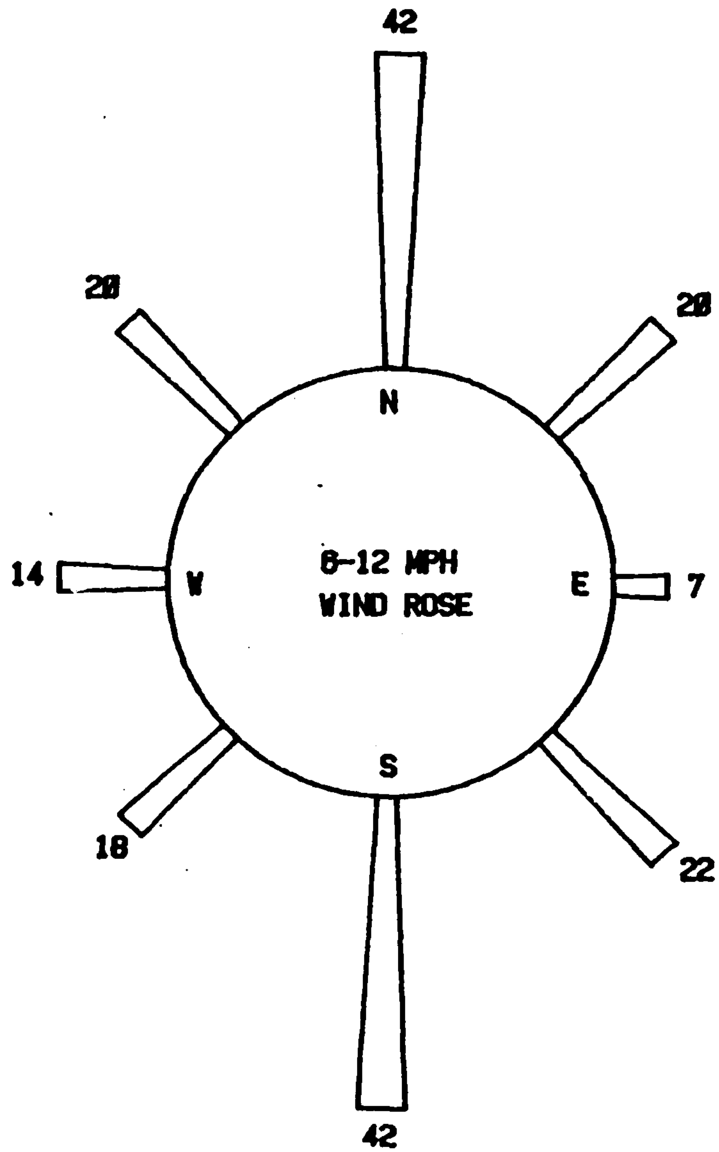
OTHER INFORMATION:
TOTAL HRS: 592



LEGEND
(READ CLOCKWISE)

(SLIDE 5)

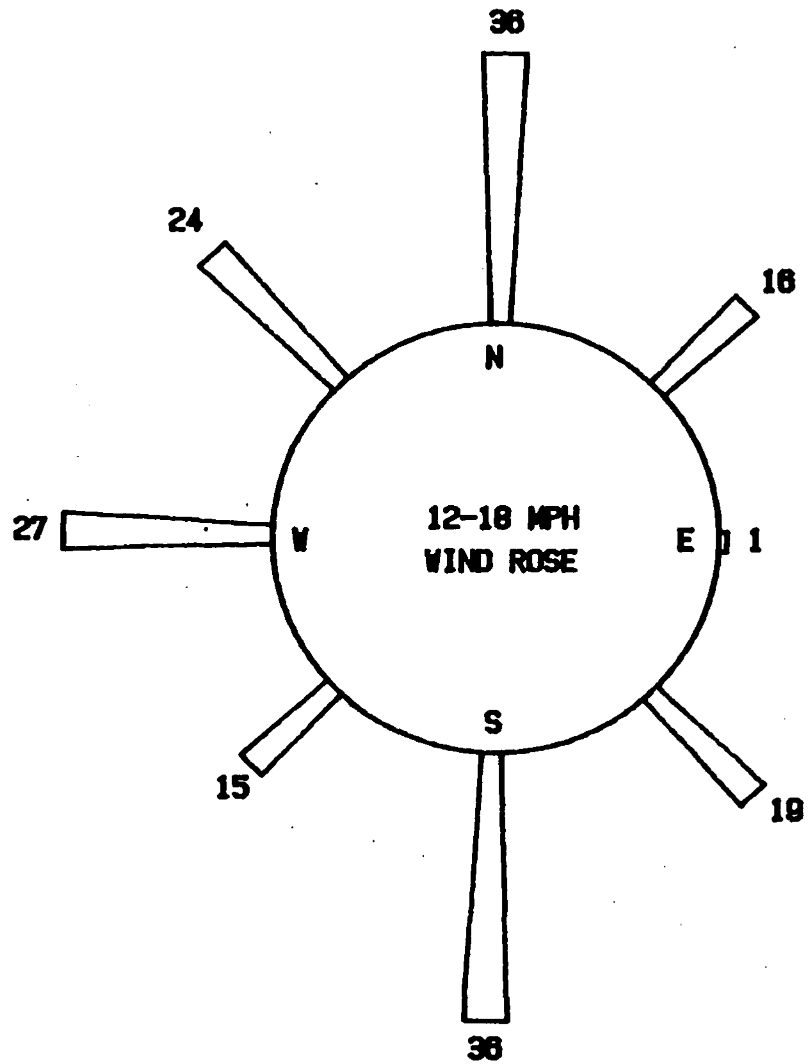
USAF ACADEMY
APRIL 1982
NORTH RIDGE TOWER
30 METERS



OTHER INFORMATION:
TOTAL HRS: 185

(SLIDE 6)

USAF ACADEMY
APRIL 1982
NORTH RIDGE TOWER
30 METERS

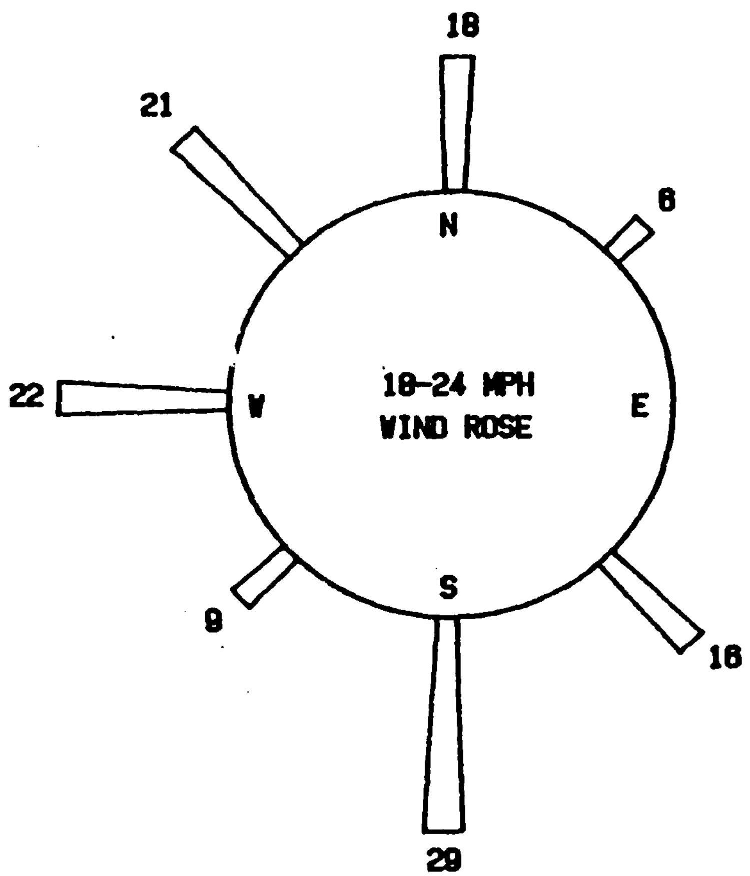


OTHER INFORMATION:
TOTAL HRS: 174

(SLIDE 7)

USAF ACADEMY
APRIL 1982
NORTH RIDGE TOWER
30 METERS

OTHER INFORMATION:
TOTAL HRS: 121

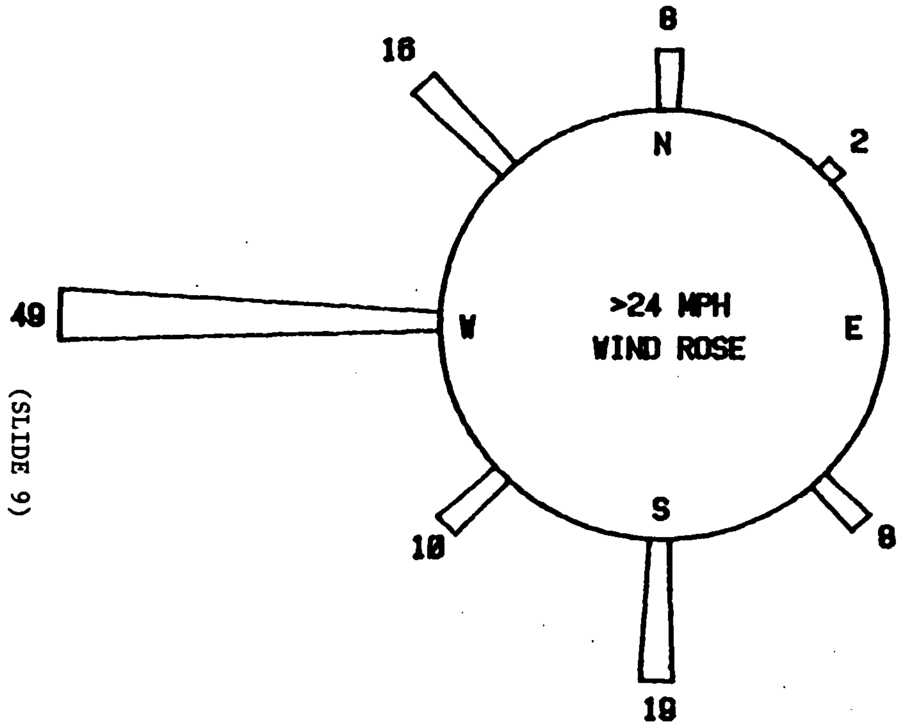


(SLIDE 8)

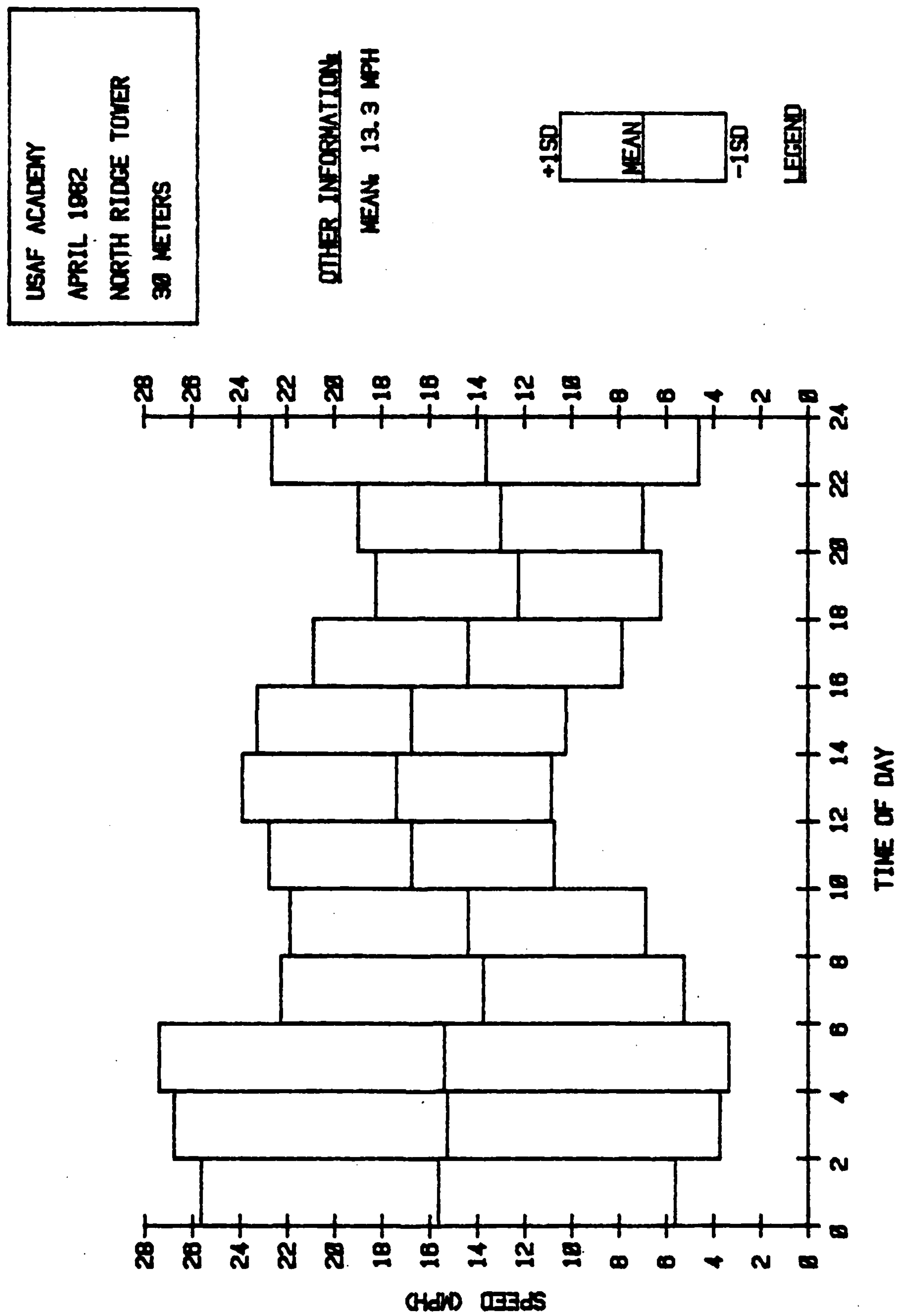
USAF ACADEMY
APRIL 1982
NORTH RIDGE TOWER
30 METERS

OTHER INFORMATION:

TOTAL HRS: 112



(SLIDE 9)


USAF ACADEMY
APRIL 1982
NORTH RIDGE TOWER
30 METERS
OTHER INFORMATION:
MEAN: 13.3 MPH
+1SD
MEAN
-1SD
LEGEND
SPEED (MPH)
TIME OF DAY
0 2 4 6 8 10 12 14 16 18 20 22 24
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28

(SLIDE 10)

[illegible]
APRIL 19[illegible]
NORTH RIDGE TOWER
30 METERS

EPROM INFORMATION

START MONTH: 4
START DAY : 1
START TIME : 11:15

STOP MONTH: 5
STOP DAY : 4
STOP TIME : 12:54

PEAK AND LULL DATA

PEAK WIND SPEED: 86.5 MPH
DAY OF PEAK WIND SPEED: 2
TIME OF PEAK WINDSPEED: 06:44
HOURS OF LULL: 11
DAY LULL ENDED: 22
TIME LULL ENDED: 08:11

WIND SPEED DISTRIBUTION
(MPH:HRS)

0- 6:	114
6- 8:	60
8-10:	61
10-12:	63
12-14:	62
14-16:	59
16-18:	55
18-20:	47
20-22:	41
22-24:	33
24-26:	26
26-28:	20
28-30:	15
30-32:	11
32-34:	9
34-36:	7
36-38:	5
>38:	20

(SLIDE 11)

WIND ROSE DATA
(MPH:HRS)

SPEED	N	NE	E	SE	S	SW	W	NW
6-12:	[illegible]	[illegible]		[illegible]	[illegible]	15	14	[illegible]
12-18:	[illegible]	16	[illegible]	19	36	15	27	[illegible]
18-24:	[illegible]	6	0	16	25	9	22	[illegible]
>24:	8	2	0	8	19	10	49	16

DIURNAL VARIATION
(TIME:MPH)

TIME	AVERAGE WIND SPEED	STANDARD DEVIATION
0000-0200:	15.6	10.0
0200-0400:	15.3	11.5
0400-0600:	15.4	12.0
0600-0800:	13.8	8.5
0800-1000:	14.4	7.5
1000-1200:	16.8	6.0
1200-1400:	17.4	6.5
1400-1600:	16.8	6.5
1600-1800:	14.4	6.5
1800-2000:	12.3	6.0
2000-2200:	13.0	6.0
2200-2400:	13.6	9.0

YAW RESPONSE
(MPH:HRS)

SPEED	SLOW	MEDIUM	FAST
6- 8:	57	2	2
8-10:	58	2	1
10-12:	60	2	1
12-14:	60	1	1
14-16:	57	1	1
16-18:	53	1	1
18-20:	46	1	0
20-22:	40	1	0
22-24:	33	0	0
24-26:	26	0	0
26-28:	20	0	0
28-30:	15	0	0
30-32:	11	0	0
32-34:	9	0	0
34-36:	6	0	0
36-38:	5	0	0

(SLIDE 12)

WIND RIGHTS

ROBERT J. NOUN

THE ACQUISITION OF WIND RIGHTS FOR WIND ENERGY DEVELOPMENT

R. J. Noun
Solar Energy Research Institute
Golden, Colorado

ABSTRACT

Identifying suitable sites for large wind machine clusters, or "wind farms," requires more than finding a location with an adequate wind resource. Consideration must also be given to the question of how land-use policies and regulations will affect the siting of wind system installations. In particular, the issue of acquiring "wind rights," or guaranteed access to the wind resource for electric power generation, will be vital to the development of wind energy. This paper examines several methods for acquiring and preserving access to the wind resource and for dealing with related land-use issues.

INTRODUCTION

Wind energy systems cannot operate without access to wind. The need to protect wind access was recognized as early as some of the first applications of wind energy became known. For example, during the Middle Ages in Europe, planting trees near windmills was banned to ensure "free wind" [1]. Until recently, there has been little concern about obstructions to the wind flow for wind machines used in the United States, since most early windmills were located on large parcels of land in rural areas. Today, as more wind energy systems are being sited in and around communities, the possiblity of interference with the flow of wind has caused wind energy developers to consider carefully how wind access can be protected over the life of the machines. Prospective investors in wind energy systems are beginning to view potential obstruction to the wind flow as a risk inherent in developing the technology; as such, it is a risk that developers now recognize must be minimized or eliminated.

In this paper, we examine methods that can be used by present and future wind energy developers to protect wind access. The examination is limited to moderate and large-size wind energy systems—30 kW to 3 MW rated capacity. In particular, we identify methods of protecting wind access for large-scale wind energy developments—clusters of machines grouped in wind farms. The paper does not address wind access issues associated with siting small wind energy systems.

The paper focuses on two approaches: (1) private, such as by negotiation of an agreement between adjacent landowners, and (2) public, such as by legislative action to protect wind access. Although the question of protecting access to the wind resource is essentially a legal one, this paper is not intended to be a definitive legal analysis of the issues involved. Rather, it provides a preliminary assessment of a variety of options, legal and legislative, that could be used to acquire and preserve wind access. Several of the approaches examined here are currently being used by wind energy developers in various parts of the country.

BACKGROUND

Several recent developments suggest the need to establish methods for protecting the wind resource for large-scale developments through legal, legislative, or regulatory means. First, wind is becoming a valuable resource for generating electricity. Some analysts believe wind energy could provide between 2% [2] and 6% [3] of the nation's electricity needs by the end of the century. But, for some utilities, the wind contribution could be much greater. In some very windy areas (e.g., Hawaii), the contribution could go higher than 10% [4].

Second, wind energy development has become big business in some parts of the country. Ninety-one U.S. utilities were involved in wind energy projects as of 1980, and 41 of those were looking into the development of large wind machines. Moreover, it is a field of rapid growth, as the number of projects has increased 80% between 1979 and 1980 [5].

Third, there is increasing evidence that the potential for large-scale wind energy development is causing land speculation in high wind resource areas throughout the country. Spiraling prices for previously useless land in Southern California's windiest desert areas, canyons, and mountain passes are an unexpected consequence of a major policy shift by the state's major utilities to wind energy development [6].

Land speculation and increased land values in high wind resource areas can substantially increase the costs of wind farm development. And, as the cost of land for the actual site of a wind farm increases, property adjacent to the proposed site will probably also increase in value. Thus, increasing land values around proposed wind farm sites may often create a situation in which upwind landowners, from whom the wind energy developer must obtain some guarantee against their later construction of buildings or vegetation that could block the wind flow to his site, demand higher prices for agreements to refrain from interfering with the flow of wind.

Finally (to ensure orderly development of a potentially valuable energy source), consideration of methods to protect wind access for wind farms will become important in high wind resource areas of the country. One recent forecast estimates that 50,000 large wind energy systems could be operating in the United States by the year 2000 [7]. Since most of these machines will be grouped in wind farms in a few high wind resource areas, the land-use implications of this magnitude of wind energy development are substantial.

CURRENT WIND FARM DEVELOPMENTS

Several wind energy development firms already have begun planning or constructing wind farms in the United States. Some of the major wind farm developments are described below:

- U.S. Windpower of Burlington, Mass., began operating the first wind farm in the U.S. in December 1980. The wind farm is located on Crotched Mountain in New Hampshire and involves a network of 20 wind turbine generators, each with 30-kW capacity and with rotor diameters of 40 feet, mounted on 60-foot towers. Spread over 25 acres, the wind machines are delivering electricity at a rate of 1.5 million kWh per year to Public Service Company of New Hampshire [8].

- U.S. Windpower has recently begun a second wind farm near Livermore, California. This farm will involve 200 wind turbines, each rated at 50 kW for a total of 10 MW. Electricity will be fed into the grid of either Pacific Gas and Electric Company or the California Department of Water Resources [9].
- In April 1981, an agreement was reached among Pacific Gas and Electric, the California Department of Water Resources, and Windfarms, Limited, a San Francisco wind energy firm, under which the two utilities would purchase electricity produced by Windfarms on cattle-grazing land in Solano County, about 30 miles northeast of San Francisco. Development of the wind farm would proceed in three phases. Commercial operation, the first step (51 machines with a combined generating capacity of 92 MW), would begin by the end of 1983 and will be complete by 1985. By the time the third stage has been finished in 1989, the cluster will include 146 wind turbine generators with an accumulated capacity of 350 MW, making it the largest wind farm planned to date in the United States [10].
- In April 1981, Hawaiian Electric Company contracted with Windfarms, Limited, to build an 80-MW, $350-million wind farm on the Island of Oahu that would supply 9% of the Island's electricity by 1985 [11].
- Also in California, wind farm developers will build more than 50 wind turbine generators as the first stage of a unique new project being promoted by Southern California Edison Company. The first stage of a wind energy "park" will be constructed over the next four years in a remote, rural area of Southern California. The first wind turbine generators should produce a total of 20 MW, enough power to serve a community of 8,000. This development is one of several planned wind parks that will help the utility meet its goal of 360 MW of wind power capacity by 1990 [12].

WIND CHARACTERISTICS

To understand the importance of wind access protection to wind energy developers, one must understand the nature of wind and how wind patterns affect the siting and performance of large wind turbine generators.

Energy in the Wind

The value to the wind energy developer of protecting an adequate flow of wind to a large cluster of wind machines can be readily determined by the dimensions of the resource. The amount of energy available in the wind critically depends on its speed, increasing by a factor of 8 every time wind speed doubles. A simple calculation shows that a 12-mile-per-hour wind contains fully 70% more power than does one of 10 miles per hour. A variation in wind speed of just 2 miles per hour can, therefore, easily mean the difference between the failure or success of a large wind energy project. Average annual wind speeds vary from less than 6 miles per hour in a few regions to nearly 20 miles per hour in some mountainous and coastal areas [13].

The Effects of Turbulence on Wind Farm Development

The motion of wind next to the ground produces friction, and this friction causes the wind near the ground to slow down. The amount that the wind is slowed depends on the roughness of the terrain and the speed of the wind, and will vary at different locations. In addition, the layer of wind nearest the surface may tumble, causing eddy currents. The size of the eddy currents will vary from less than 1 foot with low wind speeds over smooth terrain to more than 50 feet at wind speeds of 15 mph or more over rough terrain. Eddy currents interfere with normal wind flow and reduce the power a wind turbine generator can produce at a particular wind speed [14].

When wind near the ground flows over obstructions, such as a building or steep-sided hill, the normal wind profile is distorted and transformed into a complicated pattern of reverse flow, eddy currents, and other irregular air movements broadly classified as turbulence [15]. Turbulence produced by buildings, vegetation, or other wind turbine generators can affect both the quantity and quality of the wind flow to a wind energy development. The quantity of wind describes the effect of turbulence on wind speed and, therefore, on the power output of a wind turbine generator. The quality of wind describes the effect of turbulence on the structure of the wind turbine generator. The distinction between quantity and quality of wind is an important one since different machine spacing may be required within a wind farm as well as different spacing between upwind and downwind landowners to protect adequate access to the site.

Wind farm developers will need to deploy individual wind turbine generators in a configuration that will yield maximum power output consistent with load requirements and transmission line capacities. A number of factors favor locating the individual wind turbines as close together as possible. These include cost of either purchasing or leasing land for the wind turbines; ease of installation and maintenance; interconnection and transmission costs; and environmental, legal, and other considerations. However, when wind turbines are spaced too closely together, downwind machines can be influenced by the wakes of upwind machines. This influence may decrease the power output of the downwind machine because less energy is available in the oncoming wind, and may affect the structural integrity of the downwind machine because of buffeting by wake turbulence [16].

The implications for power output and structural integrity as a result of wake effects from an upwind on a downwind turbine are not, however, limited to spacing configurations within the wind farm itself. For example, suppose a developer initially determines a machine spacing configuration for a wind farm of a particular size and number of machines such that the first line of wind turbines must be situated within one or two rotor diameters from the developer's upwind neighbor. The first row of wind turbines is constructed and begins operating. Subsequently, the upwind neighbor decides to develop a wind farm of his own and determines a spacing configuration for maximum power output that calls for a row of machines only one or two rotor diameters from the downwind energy developer. Wake effects from the upwind developer's row of machines on the downwind developer's first row of machines could be substantial. The question is, how can these two competing wind farm developments be resolved in a way that will preserve adequate quantity and quality of wind for the downwind developer without precluding wind energy development by the upwind developer?

A number of studies have used numerical or physical modeling to characterize the wake of a wind turbine generator to determine the optimum spacing of wind turbine arrays, but few physical measurements have been taken around an operational large wind turbine. In

March 1980, wind energy researchers from Oregon State University conducted wind flow studies around the 200-kW Mod-OA wind turbine generator at Clayton, New Mexico. The objectives of the measurement program were to characterize the wake of the wind turbine in terms of wind speed and turbulence, and to evaluate the effects of both a nonrotating and a rotating wind turbine on the flow field. The results indicated that the wake wind speed deficits were generally largest within 4 diameters of the wind turbine generator. These deficits were on the order of 15% to 20%. At greater than 5 diameters downwind, the deficits were generally negligible; although under stable west flow, a 20% deficit was measured 7 diameters downwind. For the limited amount of data taken, the deficits approximate the wake model results measured by others [17].

In April 1981, a cluster of three Mod-2 wind turbines was put in operation by the Bonneville Power Administration of Goodnoe Hills, Washington. This is the largest array of MW-size wind systems in the world and will provide answers to many questions regarding the performance of clustered wind turbines. The three wind turbines are purposely positioned at the corners of an irregular triangle whose sides are 5, 8, and 10 rotor diameters long (1,500, 2,400, and 3,000 feet, respectively). This spacing configuration will allow researchers from Oregon State University and the Solar Energy Research Institute to study the wake effects of the machines on one another at different spacings [18].

METHODS FOR PROTECTING WIND ACCESS

Certainty is the dominant criterion for evaluating methods for protecting wind access. In examining various approaches for wind access protection, it will be useful to keep in mind some of the lessons learned from the experiences of solar energy users, states, and communities to protect solar access by these methods. However, solar and wind technologies are sufficiently different in terms of protecting access to each respective energy source that the usefulness of specific analogies to solar access is limited. Moreover, virtually all the analysis on solar access is directed to solar access protection for homeowner-scale, on-site solar energy systems. In this paper, we deal only with large-scale, centralized wind energy installations that will often pose entirely different problems associated with protecting wind access.

Private Actions

Properly drafted private agreements offer three important advantages as methods for protecting wind access: (1) such agreements are legally enforceable; (2) they offer protection with a minimum of government involvement; and (3) they permit a large degree of site-specific control over the protection afforded. The most useful private agreements for a wind energy developer are convenants and easements that bind his neighbors. The law recognizes both types of agreements; if an agreement is broken, the injured party has a judicial remedy [19].

Restrictive Covenants

If a wind energy developer has adequate capital to either purchase or lease all of the surrounding property necessary to guarantee wind access, using restrictive covenants may be the most effective way to ensure continued wind flow for the developer's installation.

One obvious limitation of this approach is the additional costs involved to the developer to control large areas of land around the proposed wind farm site. However, the developer can put the excess land to a variety of remunerative uses that would not interfere with the operation of the wind farm by including a restrictive covenant in each deed or lease that prohibits structures or vegetation above a certain height on specified areas of the property. The restrictive covenant usually binds subsequent owners of the property, but to do so it must meet certain technical requirements:

- The subsequent purchasers always must have notice of the obligations; notice is satisfied by recording the deed restrictions in the public land records.
- The person seeking enforcement usually must own some land protected by the covenant.
- The obligations of the covenant sometimes must "touch and concern" land.
- The obligations of the covenant usually must be negative (prohibiting a use or activity) rather than affirmative (requiring a landowner to take some type of action) [20].

Courts generally construe restrictive covenants narrowly and resolve ambiguities in favor of the unrestricted use of land. To avoid this result, the terms of the covenant should be defined clearly and its purpose should be described in detail [21].

Easements

If the wind energy developer lacks sufficient capital or is otherwise unable to either acquire or lease surrounding property to protect wind access, he can still negotiate individual agreements with surrounding landowners to restrict activities on their land that might reduce the quality or quantity of wind reaching the developer's installation. The wind energy developer can rely on the common-law doctrine of easements. An easement is a beneficial right that one landowner has on or over the real property of his neighbor [22]. Wind access protection can be secured either through an airspace easement or a negative easement that sets specific height and setback restrictions for vegetation and structures on the burdened property. Although each of these methods could be effective in protecting access, neither method actually creates a right to undisturbed wind flow.

An airspace easement creates a right to "space" and not the "air" or wind that occupies or passes through that space [23]. However, by purchasing an airspace easement that prohibits the burdened landowner from intruding into a designated airspace, a wind energy developer can, in effect, ensure the continued flow of wind through the space. An airspace easement for wind access would be worded as an easement to a specifically described three-dimensional space above the land of the person granting the easement that is to remain free of obstructions for the exclusive operation of the grantee's wind turbines on the benefitted property. Importantly, airspace is part of the property beneath it, under American Law [24]. Therefore, an airspace easement is an interest in real property, and as such, is recordable and will run with both the benefitted and burdened parcels to future owners or lessees.

An easement to protect wind access may also be in the form of a traditional negative easement relating to the surface of the burdened property. A negative easement would include legal descriptions of the surface of the grantor's and grantee's property and

specific restrictions on the height and setback of structures and vegetation on the burdened property.

Privately negotiated wind energy easements are, however, far from being an adequate mechanism for guaranteeing wind access:

- Easements are voluntary, and an adjoining landowner cannot be forced to sell one.
- The cost of purchasing a wind energy easement may become an important economic factor for large-scale wind energy developments. Currently, there are no accepted methods for determining the value of a wind energy easement.
- Transaction costs may also be great, especially if the developer requires legal and technical advice.
- A wind energy developer might often be forced to include several neighboring property owners in easement negotiations if wind access is to be protected adequately, because many sites will have multidirectional wind flow. As the number of landowners with whom easements must be negotiated increases, the probability of reaching an economically feasible arrangement diminishes [25].

Public Actions

Besides entering into private agreements with adjacent landowners to protect wind access, wind energy developers can seek legislative or regulatory protection at the state or local level to ensure wind access protection. The following section includes early efforts by state and local governments to address the wind access issue.

At the State Level

Legislation in Support of Private Actions. Perhaps the simplest method of providing the necessary certainty to a wind energy developer is to recognize an explicit entitlement to wind flow. Although private agreements to create airspace easements are legal everywhere in the United States, some states have enacted or are considering legislation that would explicitly recognize wind energy easements [26]. Such statutes can

- make it clear that private agreements will bind and benefit future owners of the property;
- standardize the form for recording wind energy easements, simplify their implementation, and reduce the cost of legal drafting;
- create public awareness of wind energy easements and encourage their use; and
- be politically acceptable because they cost states almost nothing [27].

Oregon is the first state in the country to explicitly recognize wind energy easements as a matter of law. The Oregon statute (1) codifies the right of receiving wind over property as an interest that can be obtained by easement; (2) defines "wind energy easement" and "wind energy conversion system"; (3) specifies that a wind energy easement runs with the burdened and benefitted real property; (4) specifies the minimum contents of a wind energy easement; and (5) makes wind energy easements recordable.

<u>Legislation in Support of Public Actions.</u> States can also provide some measure of certainty to wind energy developers by authorizing local governments to plan and regulate access to wind within their jurisdiction. For example, the recently passed Oregon law also allows city and county governments to adopt standards for protection of access to wind.

Although the Oregon state law authorizes local action and provides some limited guidelines for enacting wind access protection measures, it does not authorize or recommend measures to implement local wind access protection. However, one state has begun to consider procedures for local governments to use in regulating wind access protection. California is developing a model wind energy ordinance [28]. The model ordinance is recommended for use by both cities and counties in the state. Although the ordinance is applicable only to the regulation of small wind machines in communities, it includes a wind access provision that, if adopted or followed by local California jurisdictions, could have an impact on wind farm development in the state. The proposed wind access provision requires a wind system to be set back 7-1/2 rotor diameters from the downwind property line in the direction of the dominant wind across the site, and 2-1/2 diameters from property lines in all other directions [29].

Although this wind access provision may be well-suited to protect wind access for a subsequent small wind energy developer downwind from a person who has already put up his machine, if the 7-1/2 rotor diameter spacing were applied to large-scale wind farm developments, two problems could be anticipated.

First, a strict rotor diameter spacing to preserve wind access does not adequately take into account differences in terrain and local wind patterns that exist in different parts of the state in windy regions. While a certain rotor diameter spacing may be required for wind turbines in rough terrain, such as along mountain ridges, perhaps fewer rotor diameters would be required in areas of relatively flat terrain. Thus, a strict spacing requirement between a prospective wind energy developer's final row of wind turbines and the property line of the downwind landowner could, in some cases, preclude the developer from constructing a wind farm that maximizes energy output per unit of land.

The second potential problem with using a single (rotor diameter) spacing criterion for protecting wind access is that such a requirement does not take into account the different effects from turbulence on the quantity and quality of the wind flow to the downwind turbine sought to be protected. As mentioned, the effect of machine wake and other forms of turbulence on a downstream wind turbine may differ, depending on whether one is considering the effects on energy output or the effects on machine structure and life. For example, while 10 rotor diameters may be sufficient spacing between large machines to minimize or eliminate the momentum deficit from the upwind to the downwind turbine, minimizing the effects from the wake of an upwind turbine on the structure of the downwind turbine could be achieved by a different rotor diameter spacing.

To add a measure of flexibility to the local regulator's attempt at protecting wind access, the following suggested wind access provision might be preferred:

> Spacing of wind turbine generators in the county of ________ shall be such that the reduction in freestream velocity of the wind to a wind turbine generator downwind of another wind turbine generator at peak power shall not exceed 5% and that turbulence intensities on the downwind turbine generator shall not exceed greater than 5% more than the unaffected inflow (or ambient freestream levels) measured on the upwind side of the site.

With this language, the differences between local terrain and wind patterns at various sites in the state as well as the differences in effects of machine wake on both quantity and quality of the wind flow are recognized.

At the Local Level

Local Regulation of Wind Access. As a practical matter, it may be that in many areas in the country where wind farm development will occur over the next few years neither state nor local action will be necessary to help protect wind access. For example, in many favorable wind sites in the western United States, the development potential of property historically has been small enough that private negotiation between the wind energy developer and adjacent landowners should be sufficient to provide adequate protection for a wind farm.

However, an unexpected result of both federal and state wind resource assessment efforts to determine suitable sites for wind energy generation has been the identification of high wind resource areas in various parts of the country [30]. As high wind resource areas have been identified, wind energy developers have moved quickly to buy or lease sufficient land in those areas for development of wind farms. Because some of the best wind sites identified to date are in areas long protected for scenic, recreation, or other values, the land-use implications of large-scale wind development on these lands are significant. Moreover, some of the high resource areas, such as Riverside County, California, are sufficiently close to populated areas that competing land uses and developmental potential of property adjacent to or near proposed wind sites necessarily become siting issues for the developer.

Recognition of the need to regulate wind energy development locally has led to the first attempt by a local government in the United States to establish a system by which large-scale wind farm development can proceed. The County of Riverside, California, has proposed to establish wind resource development evalution criteria in its new general plan and land-use ordinance. The criteria would initially be established in the San Gorgonio wind resource area, which is located partially in the San Gorgonio Pass and partially in the upper Coachella Valley. The criteria would define situations in which wind turbine generation may take place and those conditions under which development may occur [31].

At this writing, the Riverside County plan is in a very early stage of development. However, it would seem that the County will be faced with making a difficult choice among several options for protecting wind access in the context of land-use planning and regulation. The choice could be among four options: (1) do nothing and leave wind

access protection up to private negotiation between adjacent landowners; (2) allow wind energy development to proceed on a "first-come, first-served" basis, perhaps under a water law, prior appropriation-type theory; (3) regulate wind access as a method of allocating the wind resource to maximize the contribution of wind energy to satisfying electricity needs of the County; or (4) develop a wind access provision in its local land use ordinance similar to the one suggested by the State of California, setting a certain number of rotor diameters as minimum spacing between wind turbines and property lines. Whatever approach the county ultimately takes, the process of developing wind access criteria as part of the larger effort at regulating large-scale wind development at the local level will undoubtedly set a precedent for California and perhaps for the rest of the country.

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THIRD-PARTY CONTRACTS

HOWARD SKLAR

(See: Sklar, H. and R. Noun, Analysis of Air Force Base Energy Acquisitions Through Third-Party Contracts, SERI/TR-211-1669, Solar Energy Research Institute, Golden, Colorado, July 1982.)

ELECTROMAGNETIC COMPATABILITY

AND

WIND ENERGY CONVERSION SYSTEMS

N. KELLEY

ElectroMagnetic Compatibility

&

WIND ENERGY CONVERSION SYSTEMS

SERI
Solar Energy Research Institute

Characteristics of WECS-induced EMI . . .

- WECS EMI IS A REFLECTED OR ECHO-TYPE INTERFERENCE PHENOMENON PRODUCED BOTH THE WECS SUPPORT TOWER AND NON-ROTATING BLADES (STATIC CASE), AND

- A TIME-VARYING INTERFERING SIGNAL (MULTIPATH) IN SYNCHRONIZATION WITH THE ROTATION RATE OF THE BLADES.

Effects of Frequency and Modulation . . .

- THE WECS INTERFERENCE PRODUCES AN AMPLITUDE MODULATED WAVE FORM IN THE DISTORTED RECEIVED SIGNAL.

- THE INTERFERENCE INCREASES WITH INCREASING FREQUENCY.

- SYSTEMS USING AMPLITUDE MODULATION MORE LIKELY TO BE INTERFERRED WITH.

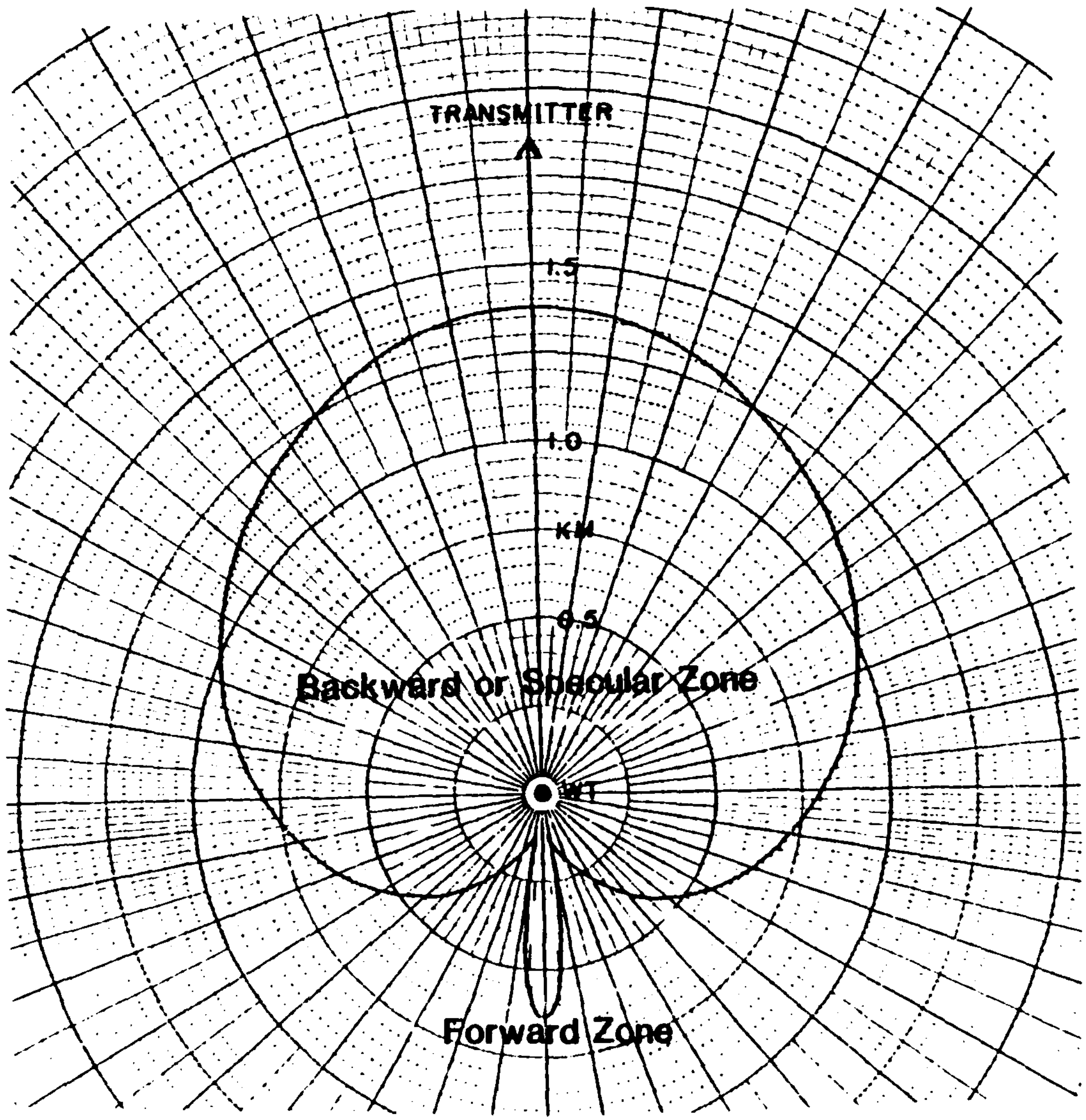
Interference Radiation Patterns . . .

- EM ENERGY FROM THE TRANSMITTER IN A COMM SYSTEM STRIKES THE WECS BLADES AND IS SCATTERED IN TWO DIRECTIONS:

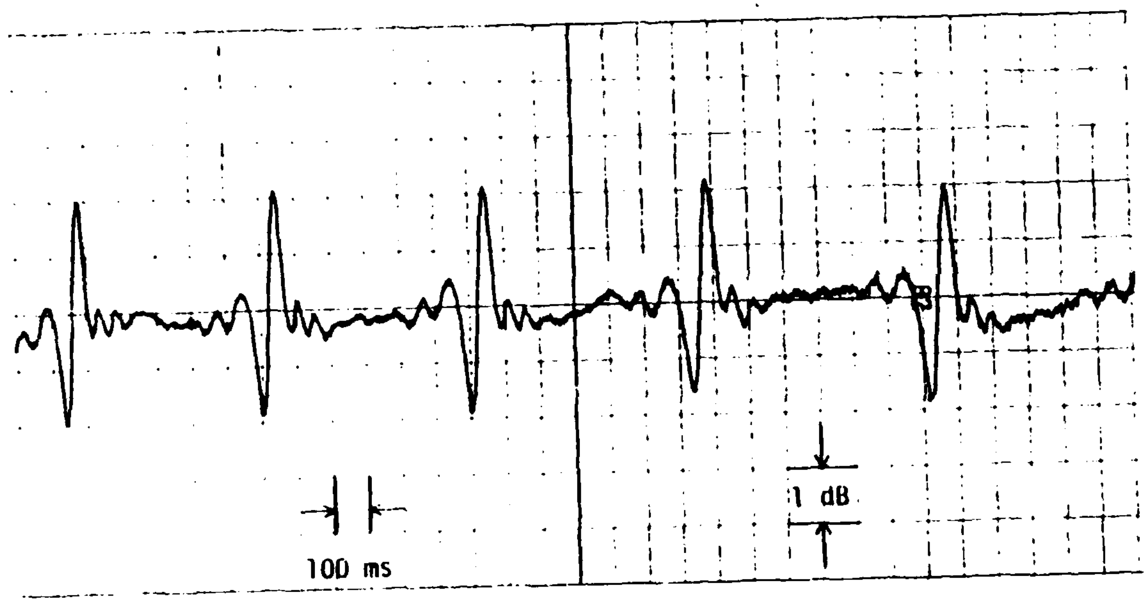
    BACKWARD OR SPECULAR SCATTERING AND

    FORWARD SCATTERING (TOWARDS RECEIVER).

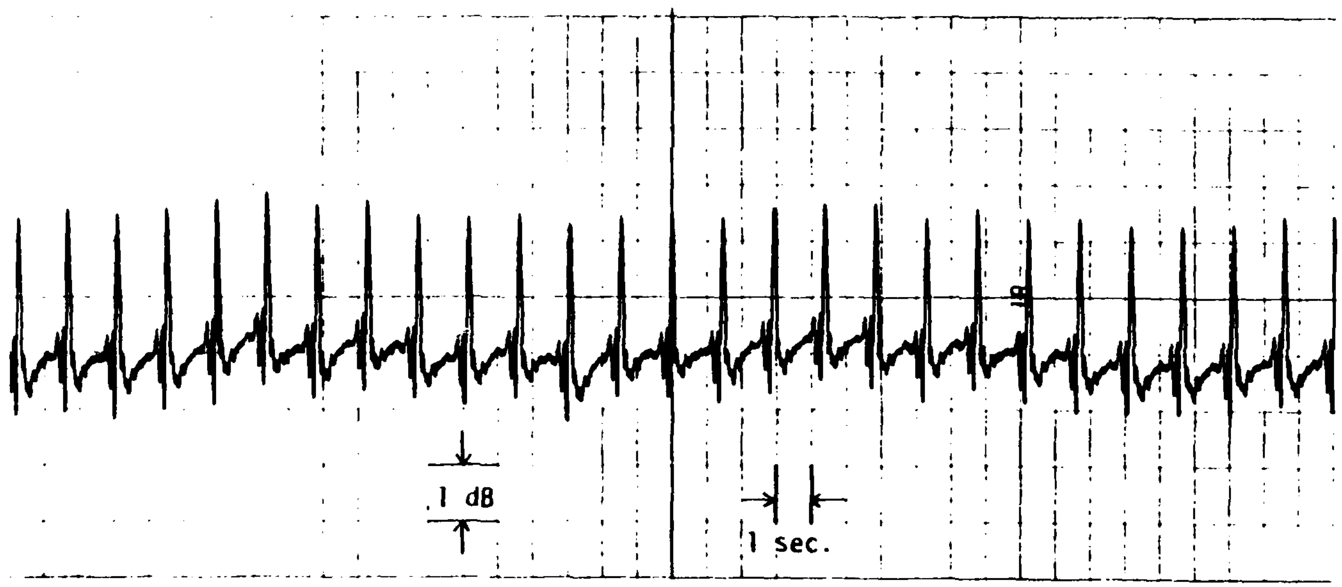
Typical Interference Zones-Television Bands . . .



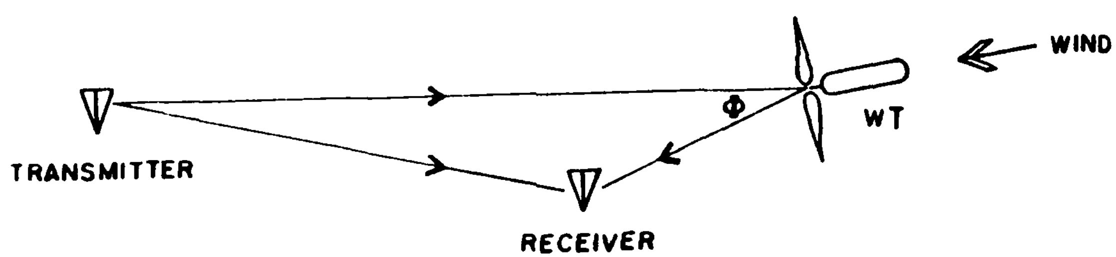
Example of Back (Specular) Scattered WECS EMI



Example of Forward Scattered Interference Waveform



WECS Television Interference Geometry



WECS EMI Knowledge of Interest to USAF Planners . . .

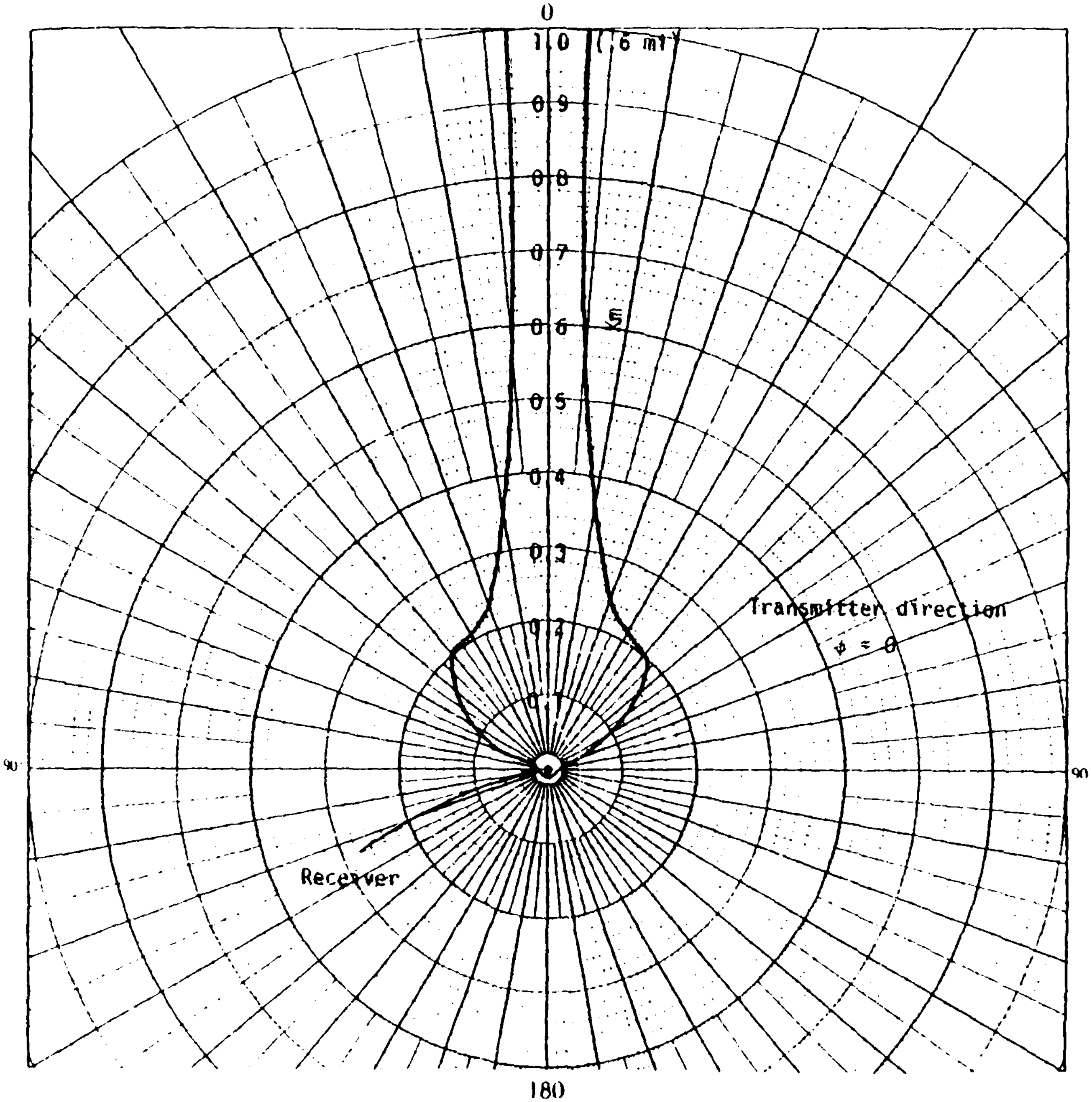
- COMMERCIAL TELEVISION BROADCASTING

  WELL UNDERSTOOD BOTH PHYSICALLY AND THEORETICALLY

- AIR NAVIGATION SYSTEMS

VOR/DVOR:	THEORETICAL STUDIES HAVE BEEN COMPLETED
TACAN:	THEORETICAL STUDIES FOR SWECS HAVE BEEN COMPLETED
ILS:	NO KNOWN STUDIES HAVE BEEN ACCOMPLISHED
LORAN-C:	THEORETICAL STUDIES HAVE BEEN COMPLETED
RADAR:	NO KNOWN STUDIES HAVE BEEN UNDERTAKEN
IFF:	NO KNOWN STUDIES HAVE BEEN UNDERTAKEN

Forbidden Zone
for a 4 GHz
Microwave Link



AD-A130 697 PROCEEDINGS OF THE UNITED STATES AIR FORCE AND TRI-SERVICE WIND ENERGY WORKSHOP AND CONFERENCE 31 AUGUST-2 SEPTEMBER 1982(U) T E KULLGREN APR 83 2/2

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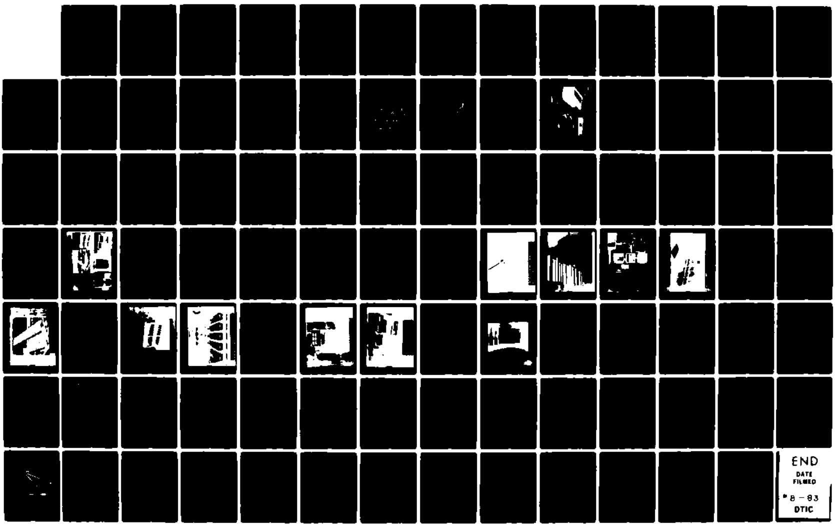
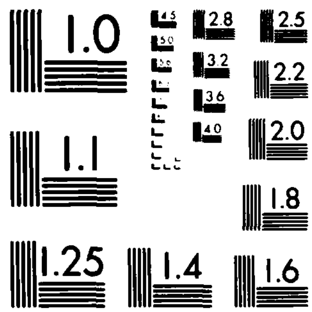




MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS 1963-A

- TELECOMMUNICATION SYSTEMS

FOR TRANSFERING: VOICE, DIGITAL DATA, CRYPTO, ETC.

SHORT RANGE (VHF/UHF): NO KNOWN CURRENT STUDIES

LONG RANGE (HF, TROPOSCATTER): NO KNOWN STUDIES

POINT-TO-POINT (MICROWAVE): UNIV OF MICH THEORETICAL STUDIES OF TD/FDM SYSTEMS

SATELLITE DOWNLINK: NO KNOWN CURRENT STUDIES

Factors Needed for Planning WECS Installations . . .

- OPERATING FREQUENCY OF RADIATED EM SYSTEM
- TYPE OF MODULATION USED (AM, FM, SSB, ETC.)
- RECEIVING ANTENNA RADIATION PATTERN
- TYPE OF DATA BEING SENT (VOICE, DIGITAL DATA, ETC.)
- PHYSICAL SIZE OF WIND TURBINE (TOWER AND BLADE DIMENSIONS)
- ROTATION RATE OF WIND TURBINE ROTOR
- LOCATION OF WIND TURBINE WITH RESPECT TO RECEIVER/TRANSMITTER
- TERRAIN SURROUNDING WECS AND RECEIVER INSTALLATIONS

What is Needed . . .

- DEVELOP A METHODOLOGY TO IDENTIFY RADIATED EM SYSTEMS IN USAF INVENTORY WHICH ARE SUSCEPTABLE TO WECS-INDUCED EMI

- DEVELOP SUITABLE INTERFERENCE CRITERIA FOR SUSCEPTABLE SYSTEMS AND INTEGRATE WITH WIND RESOURCE PLANNING ACTIVITIES AT POTENTIAL SITE LOCATIONS

- AUTOMATE EMI SITING OPERATIONS USING SPECIFIC RECEIVER MODELS FOR VARIOUS TYPES OF C-E, RADIATED EM SYSTEMS IN USAF INVENTORY.

In Particular, We Suggest . . .

- THE DEVELOPMENT OF SITING MODELS WHICH INCLUDE THE EFFECTS OF WECS-INDUCED EMI IN SPECIFIC RECEIVER MODELS AND HAVE THE ABILITY TO INCORPORATE LOCAL EM ENVIRONMENTS AS DEFINED BY SUITABLE DATA BASES PLUS WIND RESOURCES TO INDICATE THE OPTIMUM LOCATIONS OF WECS INSTALLATIONS.

- THE OBTAINING AND CATALOGING OF THE EM REFLECTIVE PROPERTIES OF A WIDE RANGE OF WECS BLADE MATERIALS FOR SMALL, MEDIUM, AND LARGE-SCALE TURBINES.

- DEVELOP THE ABILITY TO SITE A GIVEN SIZE TURBINE OR SPECIFIC DESIGN TO A SPECIFIC LOCAL USING THE ABOVE TECHNIQUES AND INFORMATION.

Resources . . .

- ELECTROMAGNETIC COMPATIBILITY ANALYSIS CENTER (ECAC)

  * TERRAIN SENSIVITY PROPAGATION MODELS
  * RECEIVER MODELING CAPABILITY - DYNAMIC AND STATIC
  * DATA BASES OF EM EQUIPMENT IN USE AT USAF INSTALLATIONS
  * COMPUTERIZED ENVIRONMENTAL ANALYSIS SYSTEMS (NEED TO BE EXPANDED FOR ECHO-TYPE EMI)
  * SENIOR ENGINEERING PERSONNEL FAMILIAR WITH WECS-EMI
  * ALSO PROVIDE ELECTRICAL AND POWER SYSTEM EMI SUPPORT FOR WECS

- UNIVERSITY OF MICHIGAN RADIATION LABORATORY

  * PERFORMED MOST MAJOR RESEARCH INTO WECS-INDUCED EMI TO DATE
  * PRIMARILY A RESEARCH GROUP HIGHLY CAPABLE OF DEVELOPING ANSWERS TO DETAILED EMI QUESTIONS REGARDING WECS.

REMOTE SITE APPLICATIONS

LT COL THOMAS E. KULLGREN

Considerable wind resource potential may exist at Air Force remote sites, particularly those outside the continental United States. This resource is difficult to quantify because comprehensive wind data is not available. However, a few sources do exist with which some estimates can be made.

Slide 1 shows USAF sites with savings-to-investment ratios greater than one which were considered in the Federal Application Study under provisions of the Wind Energy Systems Act of 1980. Noticeably missing are promising remote sites in Canada, Europe, the Mid-East and the Pacific. These sites were omitted not because they are not competitive but rather because they were not submitted for consideration. This presentation attempts to fill this gap in a qualitative way.

Slide 2 lists the assumptions used in the following slides. Wind resource data, when available, was from ESL-TR-79-21. If not available, the Country Wind Resource maps from a draft DOE International Resource Assessment were used to estimate the wind class. Only non-CONUS sites were considered.

Four average wind speed classes were assumed to make a general classification of the remote sites. Slides 3 to 6 show the results where the asterisks are keyed to Slide 1. It should be noted that many misspellings of site names appear since these spellings have been perpetuated in earlier literature.

Slide 7 shows the number of sites by command and wind speed and the load in each class. Slide 8 lists the best and worst sites in each command with their corresponding estimated mean wind speed.

Captain George Kehias, Department of Civil Engineering, USAF Academy, developed a unique nomograph for estimating the economic viability of CONUS wind sites. He subsequently extended this tool for the higher costs of energy and more expensive wind machine installations likely to be found in remote areas. The result is shown in Slide 7.

Using the nomograph of Slide 9 and the assumptions of Slide 10, a rough estimate can be made about the economic viability of remote site wind installations. Slide 10 summarizes these results by showing the maximum installed cost of equipment which would yield 10 or 20 years to simple payback at the best and worst sites of Slide 8.

The potential seems to exist for economically competitive wind machine installations at USAF remote sites. Further investigation should be undertaken to gain a better understanding of the resource and of other factors affecting such installations.

COST-COMPETITIVE AIR FORCE SITES
(DETAILED ANALYSIS)

AF FACILITY	ANNUAL LOAD (MWH)	CAPACITY (KW)	SIR
PINON PEAK, CA	132	25	8.33
ATKA, AK	300	25	3.38
CAPE LISBURN, AK	6,000	250	1.93
CAPE ROMANZOF, AK	"	"	"
COLD BAY, AK	"	"	"
TIN CITY, AK	"	"	"
ASCENSION IS	"	"	"
SHEMYA/ATKA, AK	55,800	7,500	1.92
MT. VERNON, NH	24,000	2,500	1.44
WHEELER, HI	24,300	2,500	1.29
BELLOUS, HI	"	"	"
KAALO, HI	"	"	"
KOKEE, HI	"	"	"
PUNAMANO, HI	"	"	"
GEORGE, CA	44,700	7,500	1.06
TRAVIS, CA	73,800	12,500	1.06

(SLIDE 1)

REMOTE SITES

Assumptions

- Definition: Requires remote logistical support

- Sources used

  - ESL-TR-79-21, Survivability of Remote Site Alternate Energy Systems, Vol II - Air Force Remote Sites

  - Draft SERI/DOE Report on Country Wind Resource Characteristics

- Average wind speeds used when actual not available as follows:

PNL Class	1	2	3	4	5-7
$\overline{V}$ range (m/sec)	< 4.4	4.4-5.1	5.1-5.6	5.6-6.0	> 6.0
$\overline{V}$ used (m/sec)	2.2	4.75	5.35	5.8	6.0
(mph)	4.9	10.6	11.9	12.9	13.4

- CONUS remote sites not included here:

  Fort Fisher, NC
  Gibbsboro, NJ
  Makah, WA
  North Truro, MA
  Point Arena, CA
  Port Austin, MI
  Lake Charles, LA

- Key

  ** Georgraphical coordinates unknown, best guess made of $\overline{V}$ or 4.9 mph assumed.

  * If wind speed was not available from ETAC; SERI/DOE Country Wind Resource Characteristics used.

(SLIDE 2)

REMOTE SITES

$\bar{V} < 6$ Mph

Name	Command	$\bar{V}$ (Mph)	Load (kW)
Adenau, Germany	AFCS	4.9*	22
Bonn, Germany	AFCS	4.9*	45
**Braudhof, Germany	AFCS	4.9*	48
**Cakmakli, Turkey	AFCS	4.9*	20
Campion AFS, AK	AAC	4.6	175
Ceggia RRL, Italy	AFCS	5.8	40
**Chelveston, England	AFCS	4.9*	24
Clear AFS, AK	ADTAC	5.8	9600
Conselve, Italy	AFCS	4.9	75
Divarbakir, Turkey	ADTAC	5.6	4500
**Erhac, Turkey	AFCS	4.9*	20
Eskisenir, Turkey	AFCS	4.9*	20
Feidberg, Germany	AFCS	4.9*	232
FOX-5	ADTAC	5.8	150
Galena AP, AK	AAC	4.5	-
Ghedi RRL, Italy	AFCS	2.4	20
Heidenheim, Germany	AFCS	4.9*	48
John Hoy AS, Phillipines	PACAF	5.4	750
Karatas, Turkey	AFCS	2.3	250
**Kosterberg, Germany	AFCS	4.9*	22
**Langerkopf, Germany	AFCS	4.9*	350
**Le Chenoi, Belgium	AFCS	4.9*	22
**Muehl Zuesch, Germany	AFCS	4.9*	100
**Ortakoy, Turkey	AFCS	4.9*	25
Rimini RRL, Italy	AFCS	3.8	75
**St. Mawgan, England	AFCS	4.9*	45
**Schwanberg, Germany	AFCS	4.9*	48
Schwarzenborn, Germany	AFCS	4.9*	22
Schoenfeld, Germany	AFCS	4.9*	200
**Spa Mal Champ, Belgium	AFCS	4.9*	22
Sparrevohn AFS, AK	AAC	5.4	150
Tatalina AFS, AK	AAC	4.9	150

(SLIDE 3)

REMOTE SITES

$6 \leq \bar{V} < 10.0$ Mph

Name	Command	$\bar{V}$ (Mph)	Load (kW)
Ankara ASN, Turkey	AFCS	6.7	160
Arakos RRL, Greece	AFCS	6.2	60
BAR-2	ADTAC	9.7	94
BAR-4	ADTAC	9.8	140
CAM-3	ADTAC	9.8	160
CAM-4	ADTAC	9.2	155
CAM-5	ADTAC	7.3	175
DYE-Main	ADTAC	9.0	310
DYE-1	ADTAC	8.5	400
Elmadag RRL, Turkey	AFCS	6.7	450
Estaca DeVares, Spain	AFCS	7.3	100
Fort Yukon AFS, AK	AAC	7.6	125
Humosa RRL, Spain	AFCS	6.7	250
Indian Mountain AFS, AK	AAC	6.2	150
Iraklion AB, Greece	AFCS	8.1	25
**"J" Site, Thule, Greenland	ADTAC	7.6	9600
Kubis NGB, AK	AAC	6.4	-
Monte Venda RRL, Italy	AFCS	9.8	32
Murted RRL, Turkey	AFCS	6.7	20
PIN-2	ADTAC	9.2	210
Sandrestrom, Greenland	ADTAC	7.9	1800
Thule, Greenland	ADTAC	7.6	6000
Wallace Island, PI	PACAF	7.5	1700
Woomera, Australia	ADTAC	8.5	900

(SLIDE 4)

REMOTE SITES

$10.0 \leq \overline{V} < 12.0$ Mph

Name	Command	$\overline{V}$ (Mph)	Load (kW)
**Almedag, Turkey	AFCS	10.6*	20
**Arygroupolis, Greece	AFCS	10.6*	20
Balikesir, Turkey	AFCS	10.6*	100
Barford St. John, England	AFCS	11.9*	600
Barkway, England	AFCS	11.9*	24
BAR-1	ADTAC	10.1	160
BAR-3	ADTAC	10.1	160
Ben Ahin, Belgium	AFCS	10.6*	22
Botley Hill, England	AFCS	11.9*	45
Bowington, England	AFCS	11.9*	440
CAM-Main	ADTAC	11.9	440
Cape Newenham AFS, AK	AAC	11.3	150
Christmas Common, England	AFCS	11.9*	24
Cold Blow, England	AFCS	11.9*	15
Corlu, Turkey	AFCS	10.6*	20
Doventry, England	AFCS	11.9*	24
Dunkirk, England	AFCS	11.9*	24
DYE-4	ADTAC	11.2	675
Erzurum, Turkey	AFCS	11.9*	30
Flobeq, Belgium	AFCS	10.6*	22
FOX-2	ADTAC	10.2	180
FOX-3	ADTAC	11.6	190
FOX-4	ADTAC	11.5	160
Great Brawley, England	AFCS	11.9*	24
High Wycombe, England	AFCS	11.9*	45
Houtem, Belgium	AFCS	10.6*	22
Izmit, Turkey	AFCS	10.6*	20
King Salmon AP, AK	AAC	10.5	500
Levkas, Greece	AFCS	10.6*	300
Martleshan, England	AFCS	10.6*	520
Menorca RRL, Spain	AFCS	10.0	250
**Mt. Edheri, Greece	AFCS	10.6*	150
**Mt. Hortiatis, Greece	AFCS	10.6*	100
"P" Mountain, Greenland	ADTAC	10.4	600
Pateras RRL, Greece	AFCS	10.6*	350
**Pervolakie, Greece	AFCS	10.6*	20
PIN-1	ADTAC	10.6	190
Rothwesten, Germany	AFCS	10.6*	22
Sahin Tepesi, Turkey	AFCS	10.6*	300
Samsun, Turkey	AFCS	10.6*	250
Sinop, Turkey	AFCS	10.1	20
Swingate, England	AFCS	11.9*	15
Uxbridge, England	AFCS	11.9*	250
Westrozebke, Belgium	AFCS	10.6*	22
Yalova, Turkey	AFCS	10.6*	20

(SLIDE 5)

REMOTE SITES

$\overline{V} > 12.0$

Name	Command	$\overline{V}$ (Mph)	Load (kW)
BAR-Main	ADTAC	12.9	600
CAM-1	ADTAC	12.6	80
CAM-2	ADTAC	12.1	150
Cape Lisburne AFS, AK	AAC	12.1	150
Cape Romauzof AFS, AK	AAC	13.5	150
Cima Gallina RRL, Italy	AFCS	17.0	-
Cold Bay AFS, AK	AAC	16.8	100
DYE-2	ADTAC	16.9	475
DYE-3	ADTAC	12.9	475
FOX-Main	ADTAC	13.0	1000
**H-1	ADTAC	14.7	500
H-3	ADTAC	12.3	350
Inoges, Spain	AFCS	14.4	200
Johnston Island, Pacific Ocean	DOE	16.0	2750
Kotzebue AFS, AK	AAC	12.8	100
LIZ-2	ADTAC	12.1	130
LIZ-3	ADTAC	12.2	120
Malatya, Turkey	AFCS	12.9*	350
Martina Franca, Italy	AFCS	13.4*	300
Monte Calvarina, Italy	AFCS	13.4*	20
Monte Cimone RRL, Italy	AFCS	19.3	32
Monte Corona, Italy	AFCS	13.4*	65
Monte Limbara RRL, Italy	AFCS	17.6	350
Monte Nardello, Italy	AFCS	13.4*	250
**Monte Paganella RRL, Italy	AFCS	19.3	32
Monte Vergine RRL, Italy	AFCS	16.2	350
Mormond Hill, England	AFCS	13.4*	455
Murphy Dome AFS, AK	AAC	13.9	160
Parnis RRL, Greece	AFCS	19.2	200
PIN-Main	ADTAC	12.2	340
PIN-3	ADTAC	13.6	190
PIN-4	ADTAC	12.9	165
POW-Main	ADTAC	12.2	140
POW-1	ADTAC	12.2	125
POW-2	ADTAC	12.2	170
Shemya AFB, AK	AAC	18.5	-
Soller RRL, Spain	AFCS	13.5	200
Tin City AFS, AK	AAC	17.1	150
Wake Island, Pacific Ocean	PACAF	14.0	1500
Yamanlar RRL, Turkey	AFCS	12.5	350

(SLIDE 6)

REMOTE SITES

NUMBER OF SITES BY $\bar{V}$ CLASS

	<6 MPH	$6 \leq \bar{V} < 10$	$10 \leq \bar{V} < 12$	>12
ADTAC	3	12	9	16
AFCS	24	8	34	15
AAC	4	3	2	7
PACAF	1	1	0	2
TOTAL	32	24	45	40
LOAD BY CLASS (MEGAWATTS)	17.3	23.0	7.5	10.5

(SLIDE 7)

REMOTE SITES

IN $\overline{V}$ > 12 MPH CLASS

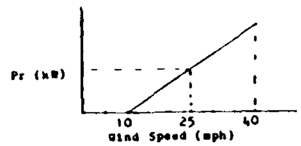
	BEST SITE, $\overline{V}$ (MPH)	WORST SITE, $\overline{V}$ (MPH)
ADTAC	DYE-2, 16	CAM-2, 12.1
AFCS	MONTE PAGAUELLA, 19.3	YAMANLAR, 12.5
AAC	SHEMYA, 18.5	CAPE LISBURNE, 12.1
PACAF	JOHNSTON ISLAND, 16.0	WAKE ISLAND, 14.0

(SLIDE 8)

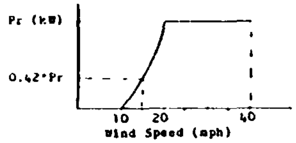
1. Average wind speed is adjusted for height using seventh power law.

2. Annual energy output is computed assuming Rayleigh distribution for wind speed and using one of three models to represent the power output of the wind machine.

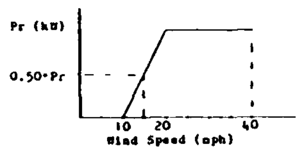
Model A:
- Operating range: 10 to 40 mph
- Output: Increases linearly over full range
- Pr: Defined as output when wind speed is 25 mph.



Model B:
- Operating range: 10 to 40 mph
- Output: Increases as a quadratic from 10 to 20
  $P(V)=(-0.375)+(6.25\times10^{-2})\cdot V+(3.125\times10^{-3})\cdot V^2$
  Constant output from 20 to 40 mph
- Pr: Constant output form 20 to 40 mph



Model C:
- Same as B EXCEPT
- Output: Increases linearly from 10 to 20 mph



EXAMPLE: A wind machine whose output best fits Model B is to be installed on a 30' tower. The constant output of the machine (Pr) is 20KW. The average wind speed at the site, measured with an anemometer at 10', is 12 mph. The cost of electricity is 80¢/kWHr and the machine can be installed for $480,000.

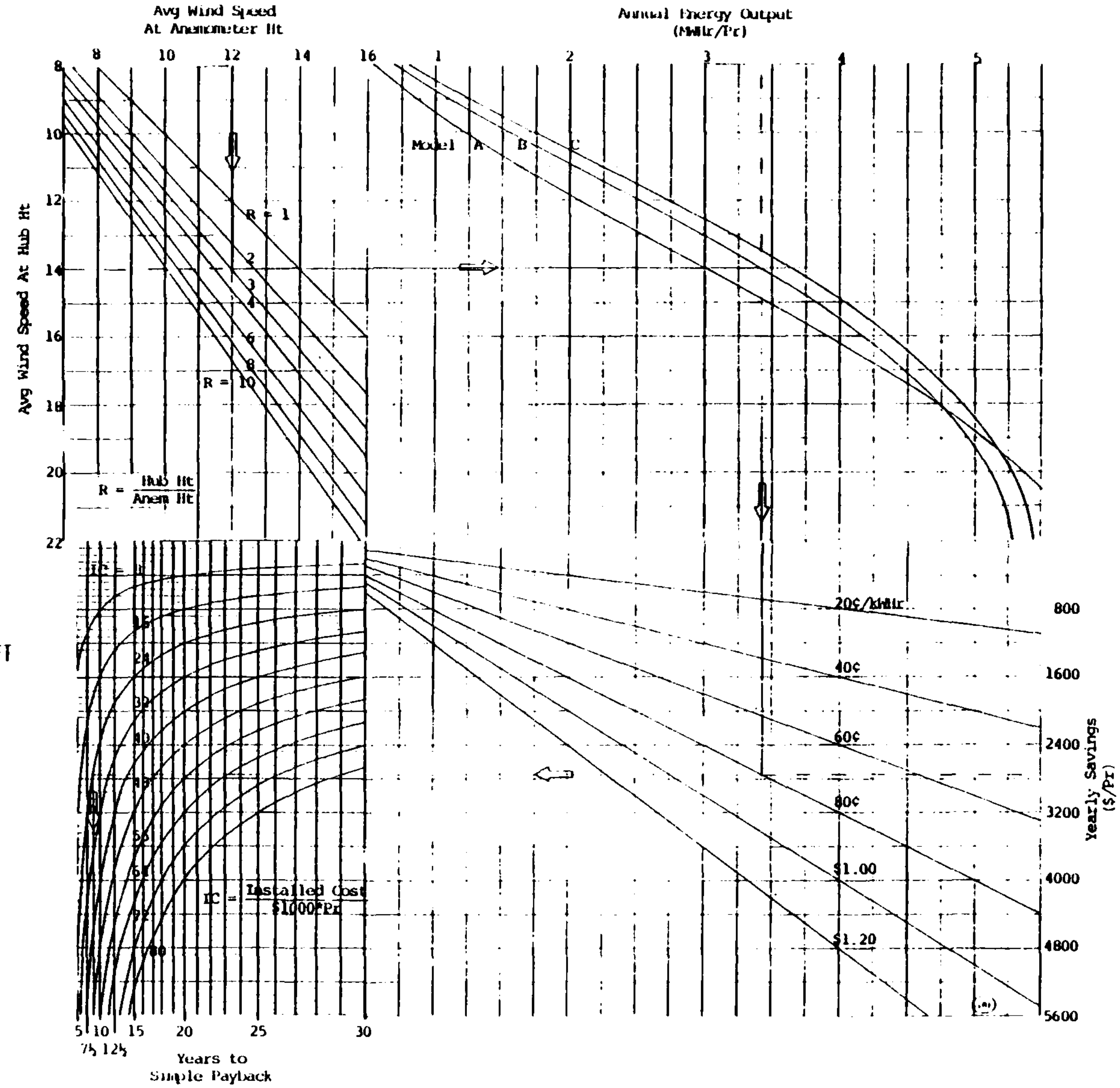
$R = \frac{30}{10} = 3$, therefore wind speed average at hub is 14.

Annual energy output = 3.4 * 20 = 68 MWHr.

Yearly savings = 345 * 20 = $55,200

$IC = \frac{\$400,000}{1000 \cdot 20} = 3$; therefore it will take approximately 8.5 years to payback cost of installing the wind machine.

DRAFT



REMOTE SITES

ASSUMPTIONS

- RECORDED WIND SPEED USED FOR HUB HEIGHT OF WIND MACHINE
- PRESENT ENERGY COST (FROM DIESEL GENERATORS) ON-SITE = $.25/kW-HR
- FUEL-POOL DIESEL @ $2/GAL
- NOMOGRAPH "MODEL B" WIND MACHINE USED

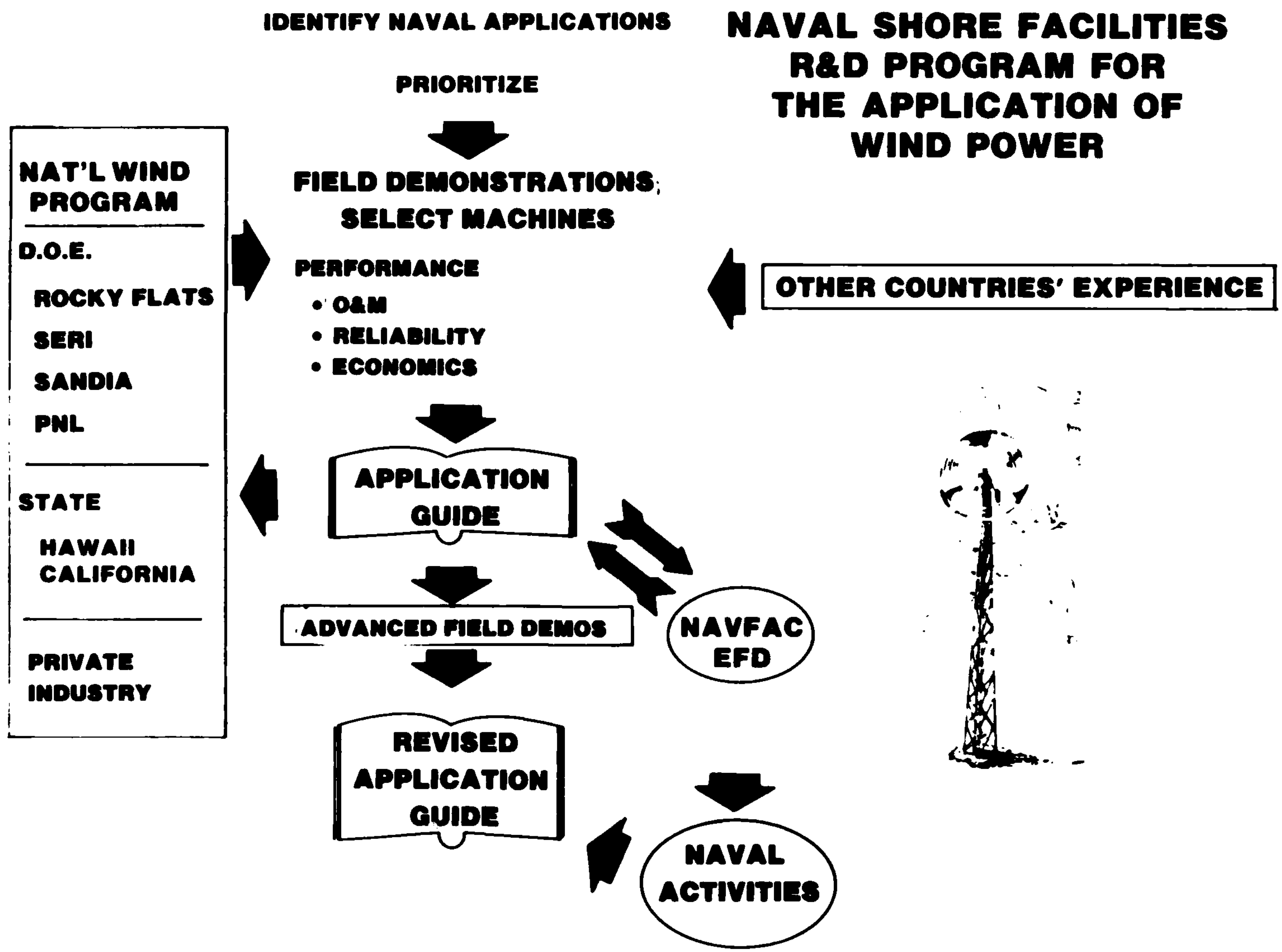
$/INSTALLED kW

	10 YEARS TO SIMPLE PAYBACK	20 YEARS TO SIMPLE PAYBACK
BEST SITE ($\bar{V}$>12 MPH)	< $10,000	< $20,000
WORST SITE ($\bar{V}$>12 MPH)	< $ 5,000	< $10,000

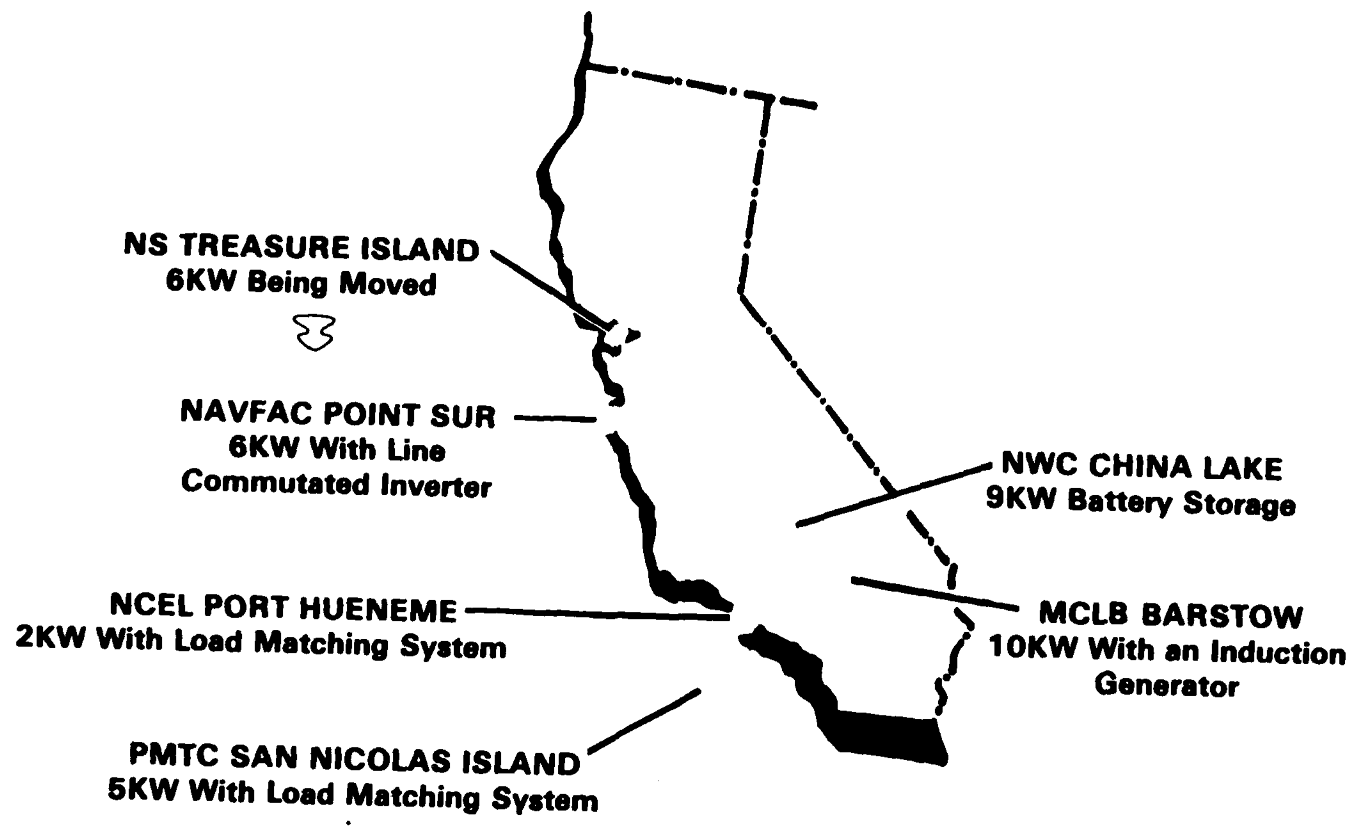
(SLIDE 10)

U.S. NAVY WIND PROGRAM

J. HELLER


NAVAL SHORE FACILITIES
R&D PROGRAM FOR
THE APPLICATION OF
WIND POWER
IDENTIFY NAVAL APPLICATIONS
PRIORITIZE
FIELD DEMONSTRATIONS;
SELECT MACHINES
PERFORMANCE
• O&M
• RELIABILITY
• ECONOMICS
OTHER COUNTRIES' EXPERIENCE
NAT'L WIND PROGRAM
D.O.E.
ROCKY FLATS
SERI
SANDIA
PNL
STATE
HAWAII
CALIFORNIA
PRIVATE INDUSTRY
APPLICATION GUIDE
ADVANCED FIELD DEMOS
NAVFAC EFD
REVISED APPLICATION GUIDE
NAVAL ACTIVITIES

WECS DEMONSTRATION SITES IN CALIFORNIA



PIÑON POINT WIND DATA

MONTH	AVERAGE SPEED MPH	WIND DIRECTION	PEAK WIND SPEED MPH
FEB*	15.2	South/Southwest	56
MARCH	10.15	South/Southwest	63.5
APRIL	11-70	South/Southwest	77.0
MAY	11-03	South/Southwest	53.5
JUNE*	8.9	South	44.8

*Not a Complete Month's Data


Hybrid Energy System
(Tudor Hill Laboratory, Bermuda)

CANDIDATE SITES FOR WIND FARM APPLICATIONS

	Average Wind Speed
• NS, Adak	16 to 18 mph
• NWS, Concord	14 to 17 mph
• NS, Pearl Harbor, Hawaii (Kole Kole Pass)	18 mph
• MCLB, Barstow	12 to 14 mph

LARGE WECS — Current Technology

- Conversion Efficiency - Good
- Reliability - Poor due to fatigue & creep hydraulic controls
- Siting - Extensive knowledge of site wind data
- Site Preparation - Extensive construction work such as roads and utility lines

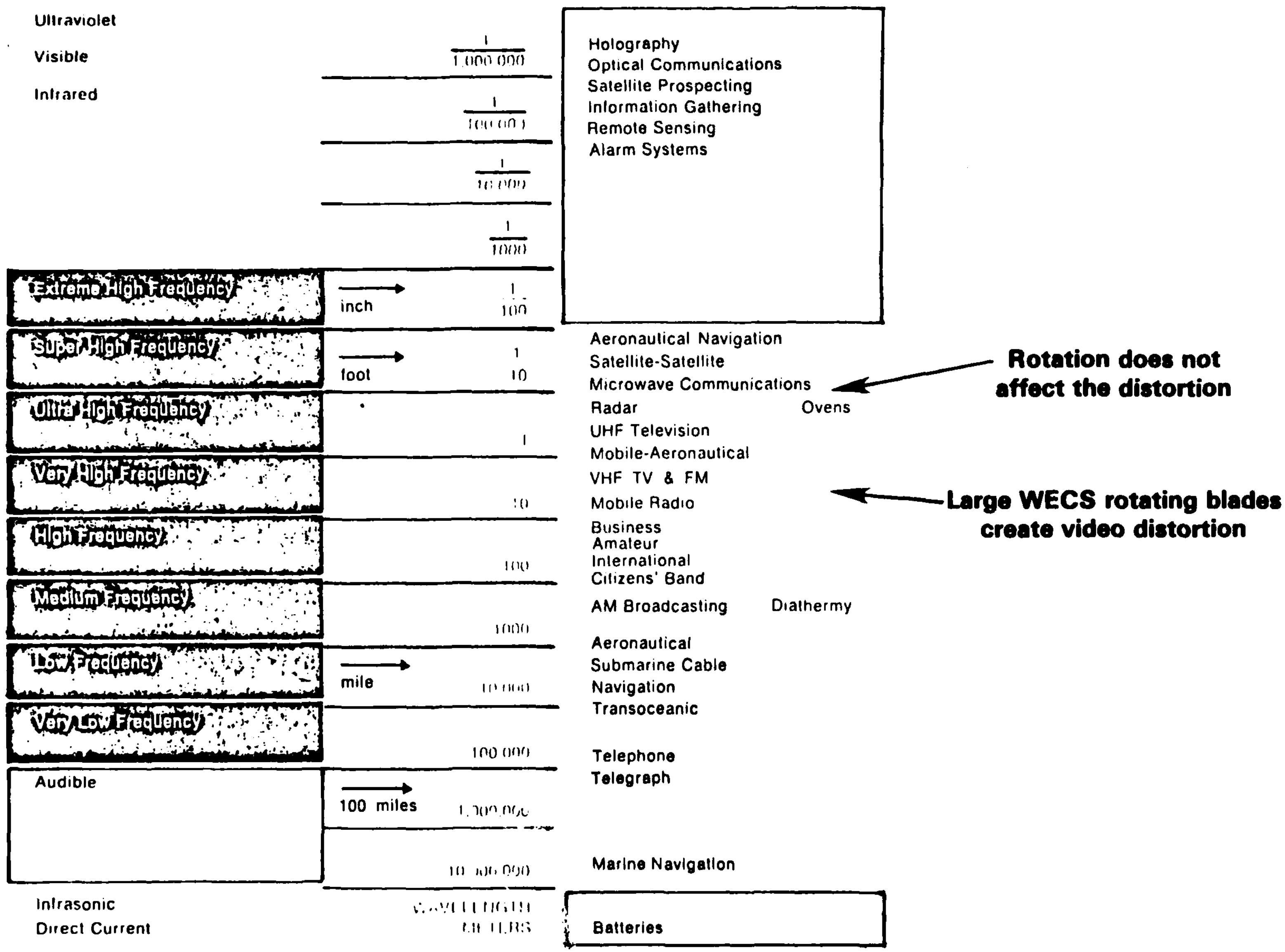
VARIOUS LARGE WECS DESIGNS

System	Rotor Diameter, Ft.	Location	Size, KW	Remarks
DOE MOD-OA	125	Kuhuku, Hawaii	200	Good Performance
MOD-2	300		2500	Improper Siting
SCE SYSTEM	175	San Gorgonio Pass	1200	Poor Performance
SWEDISH	—	Maglarp	3000	—
GERMAN	330	Growian Site	3000	Good

NAVY SPECIFIC PROBLEMS FROM LARGE WECS OPERATION

- EMI
- GRID INSTABILITY
- ACOUSTICAL NOISE

THE ELECTROMAGNETIC SPECTRUM



RELIABILITY & MAINTAINABILITY CONSIDERATIONS FOR WECS

EQUIVALANCE

	Years	Automobile Miles
Mean Time between Failures	5	1,000,000
Maintenance Frequency	0.5	100,000
Useful Life	25	5,000,000

WECS O&M EXPERIENCE RECORD

2 KW at NCEL Port Hueneme, installed July 1977

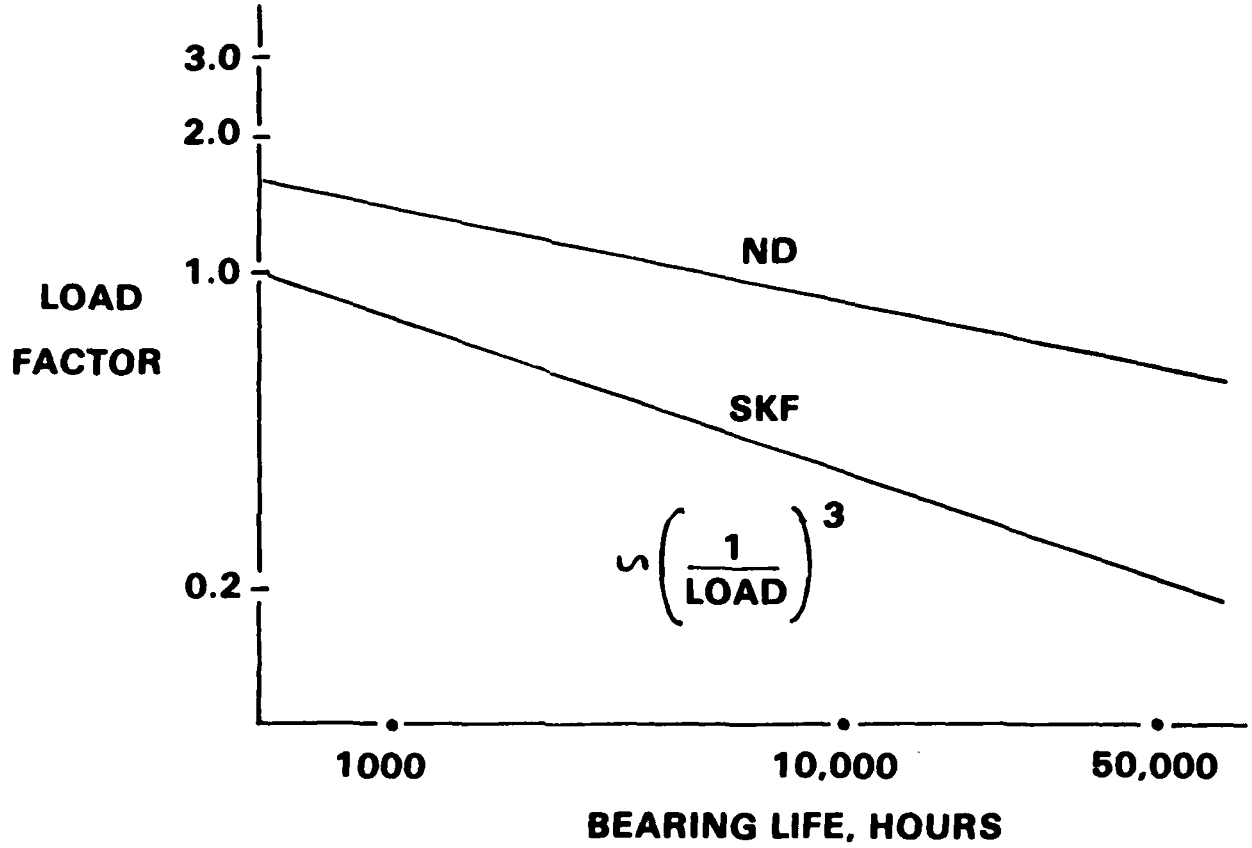
- Arcing of electrical terminals
- Yaw bearing failure
- Corrosion of blades
- Wear of nylon rollers in blade pitching mechanism
- Voltage regulator components failure
- Broken electrical wire in the field circuit

6 KW at NS Treasure Island, installed September 1979

- Arcing of electrical terminals
- Blade pitching mechanism component failure
- Synchronous inverter control circuitry failure

10 KW at NCEL Port Hueneme, installed December 1979

- Arcing of electrical terminals
- Overspeeding rotor resulted in hub, yaw bearing failures
- Corrosion of blade pitch surfaces



FATIGUE LIFE CURVES OF BEARINGS WITH ROLLING CONTACTS

ENVIRONMENTAL FACTORS WHICH AFFECT CORROSION IN WECS COMPONENTS

- Ambient temperature changes
- Salt contents of air
- Relative humidity
- Wind speed
- Solar radiation (ultraviolet)
- Dust in the air
- Rainfall
- Fog
- Pollutants in the air

FUTURE DESIGN GOALS FOR WECS

• ROTOR	Fixed Pitch
Blades	Non-Metallic
Bearings	Replacement Every 2 to 3 Years
Configurations	Upwind of Tower
• GEARBOX	Do Not Use If Absolutely Necessary, Rugged Gears
• GENERATOR	Permanent Magnet Slow Speed
• CONTROLS	Fail Safe, Passive Types
• TOWER	Guyed, Hinged for Easy Maintenance

REESE AFB WIND MACHINE INSTALLATION

R. STEEDE

WIND ENERGY IN ATC

REESE AFB

- FY 81 O&M - $85,000
- FEASIBILITY STUDY AND DESIGN BY BASE PERSONNEL/TEXAS TECH
- LIMITED SITE - AIRFIELD CLEARANCE
- 2 EA 25 KW UNITS IN GOLF COURSE VICINITY TIED TO BASE ELECTRIC GRID
- START UP: 8 JAN 82
- 22 DAYS DOWNTIME

VANCE AFB

- WIND MEASUREMENT BY USAFA TEAM - JAN 82
- MEASUREMENT TOWER AT KEGELMAN AUX - O&M FUNDS
  - -- INSTRUMENTATION SUPPLIED FROM AFESC

REESE AFB WIND ENERGY PROJECT

HISTORY

- ORIGINAL CONCEPT: 1977 OUT MCP/10-YEAR ENERGY PLAN
- FY 81 O&M FUNDING: $100,000
- FEASIBILITY STUDY AND DESIGN BY BASE PERSONNEL/TEXAS TECH

PURPOSE

- DETERMINE APPLICABILITY TO TYPICAL AF BASE
- MAINTENANCE BY IN-HOUSE FORCES
- PAYBACK NOT A FACTOR IN DECISION

INSTALLATION

- TWO EACH 25 KW UNITS: J. CARTER CO.
- VICINITY OF GOLF COURSE
- TIED TO BASE ELECTRICAL DISTRIBUTION SYSTEM

SITING/WIND INFORMATION

- SANDIA
- TEXAS TECH

SITING PROBLEMS

- AIRFIELD CLEARANCE: 80 FT LIMITATION

INDUSTRY SEARCH

- 15-20 MACHINES IN 25 KW RANGE
- BASE PERSONNEL COMPARISON/EVALUATION
  - -- TI 59 PROGRAM
  - -- "PRINCIPLES OF SOLAR ENGR" - KREITH & KREIDER
  - -- FREE PROP ANALYSIS
- J. CARTER MODEL 25 SELECTED
  - -- BEST EFFICIENCY CURVE

J. CARTER MACHINE

- 25 KW
- HORIZONTAL AXIS
- TWO BLADES
- BENEFITS
  - 25 KW @ 26 MPH WIND
  - SOME ELEC @ 7 MPH
  - FIBERGLASS BLADES
    - ELIMINATES RADIO INTERFERENCE
    - AUTOMATIC PROP FEATHERING
  - TESTED IN 125 MPH WIND WITHOUT DAMAGE
  - SINGLE POLE TOWER
    - ELIMINATES VANDALISM
  - BUILT-IN WINCH FOR LOWERING
  - SIMPLE O&M: TWICE A YEAR

INSTALLATION

- TWO MACHINES
- STRIP CHART RECORDERS
- $85,000 INSTALLED
- STARTED UP: 8 JAN 82
- TIED TO BASE POWER GRID

EXPERIENCE AS OF 24 AUG 82

- 228 DAYS OWNED/206 DAYS PRODUCTION
- PRODUCED 28,500 KW
    - BASE AV CONS = 2 MIL KW/MONTH
- ORIGINAL PAYBACK 10 YEARS

DOWNTIME

- TWO DAYS: BAD CONNECTION BETWEEN GEN AND CONTROL BOX
- TWO DAYS: BLADE FAILURE/SPAR FRACTURE
- EIGHTEEN DAYS:
    - OUTPUT SHAFT FAILURE
    - BLADE FAILURE

MAINTENANCE

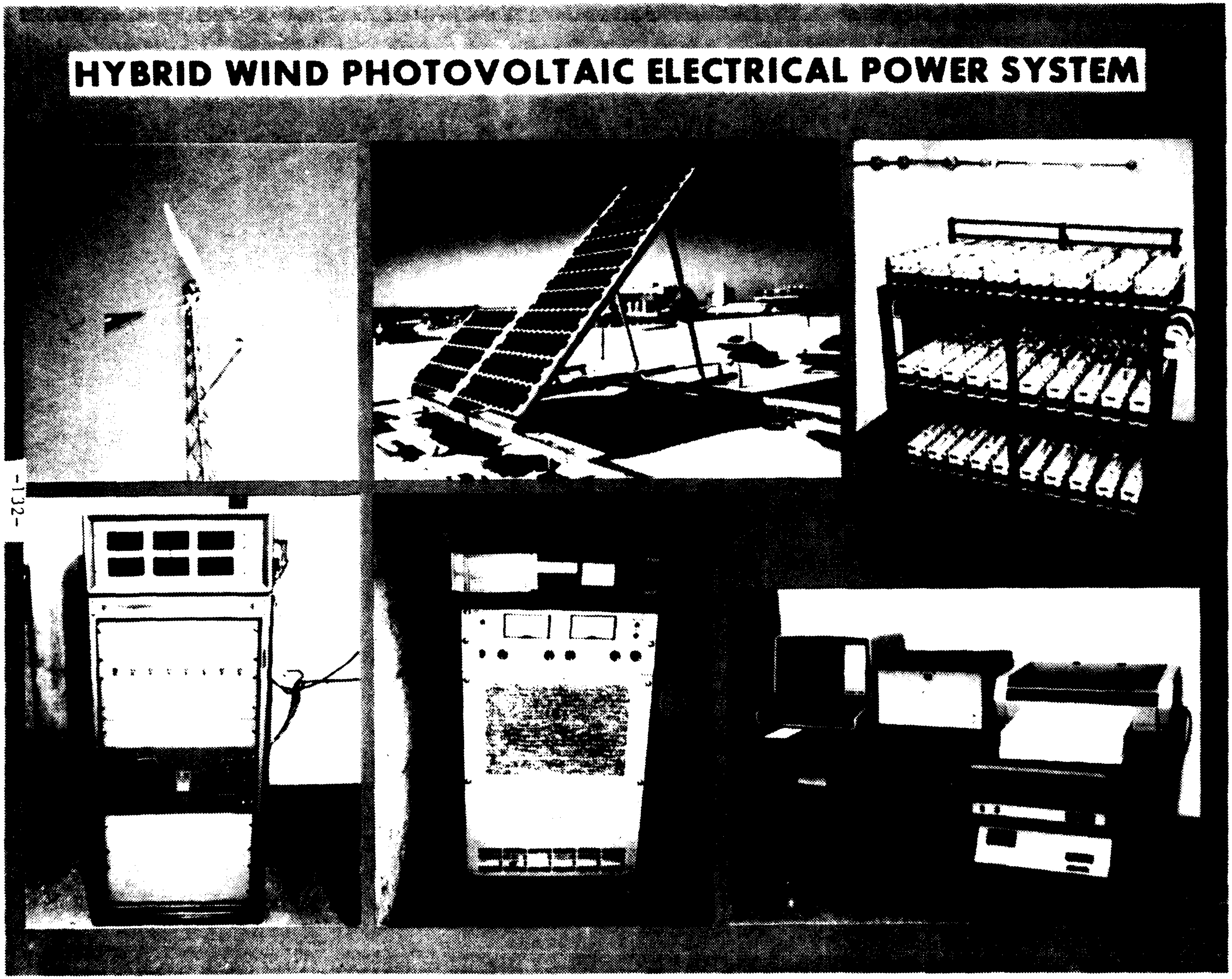
- POWER/PRO SHOP ENTHUSIASTIC
- CHECKED FROM GROUND ONCE A MONTH
- ALL PROBLEMS COVERED BY WARRANTY

BASE FEELINGS

- CLEAR ZONE PROBLEMS
- BASIC EQUIPMENT COST UP TO $30,000
- LIMITED PAYBACK

USAF/UNIVERSITY OF DAYTON WIND-SOLAR REMOTE SITE PROJECT

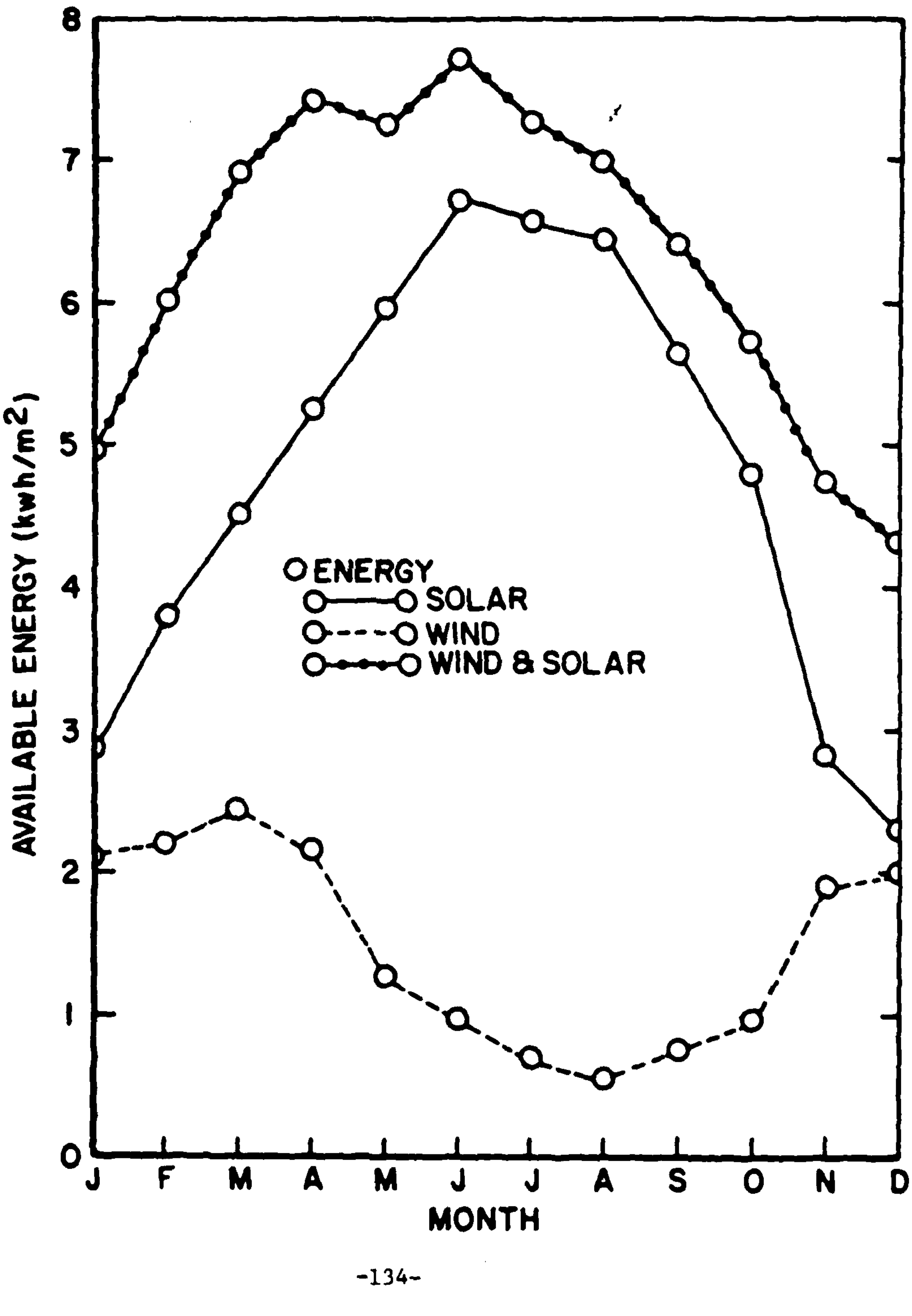
W. BISHOP

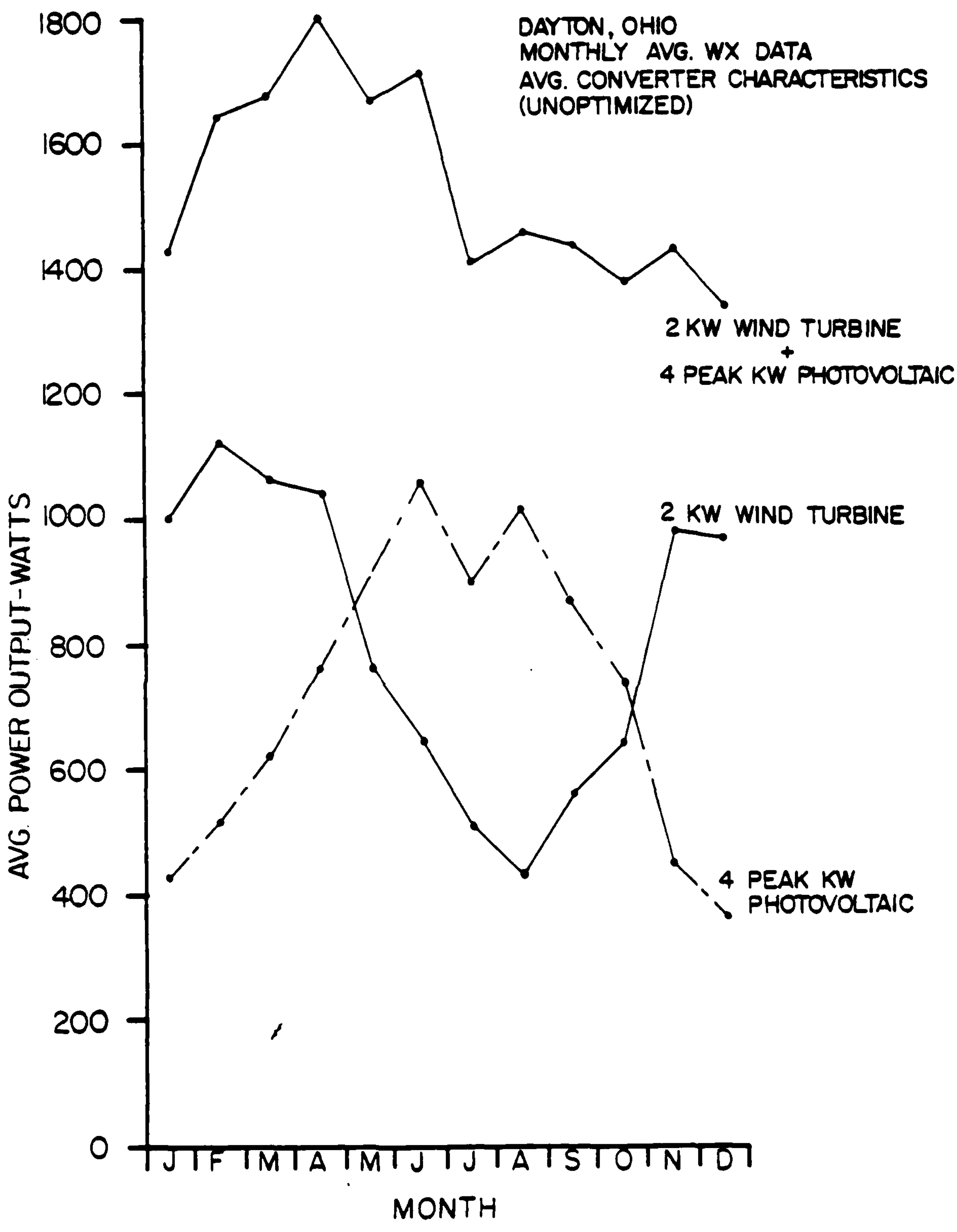

HYBRID WIND PHOTOVOLTAIC ELECTRICAL POWER SYSTEM

CONCEPT

- HYBRID SYSTEM USING SOLAR INSOLATION AND WIND POWER
- SMALL SCALE DEMONSTRATION MODULE
- SIMPLE AND RELIABLE
- IDENTIFY COST-EFFECTIVE COMBINATIONS OF WIND GENERATORS, SOLAR PHOTOVOLTAIC PANELS AND ELECTRIC BATTERY STORAGE TO SATISFY A SPECIFIED ELECTRIC LOAD IN A GIVEN LOCATION

MONTHLY SOLAR AND WIND ENERGY FOR DAYTON, OHIO




DAYTON, OHIO
MONTHLY AVG. WX DATA
AVG. CONVERTER CHARACTERISTICS
(UNOPTIMIZED)
2 KW WIND TURBINE
+
4 PEAK KW PHOTOVOLTAIC
2 KW WIND TURBINE
4 PEAK KW
PHOTOVOLTAIC
AVG. POWER OUTPUT-WATTS
1800
1600
1400
1200
1000
800
600
400
200
0
J
F
M
A
M
J
J
A
S
O
N
D
MONTH

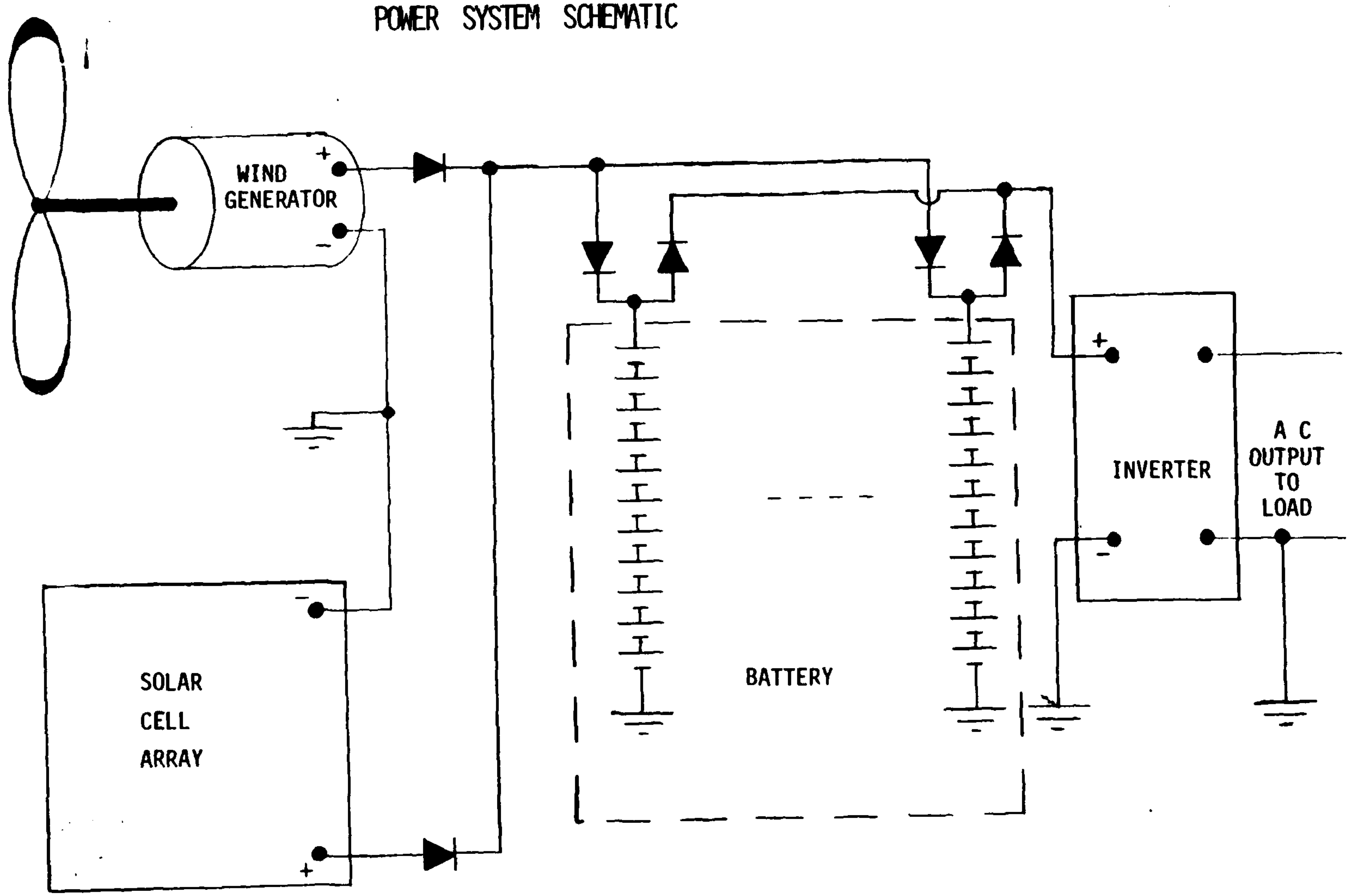
EXPERIMENTAL OBJECTIVES

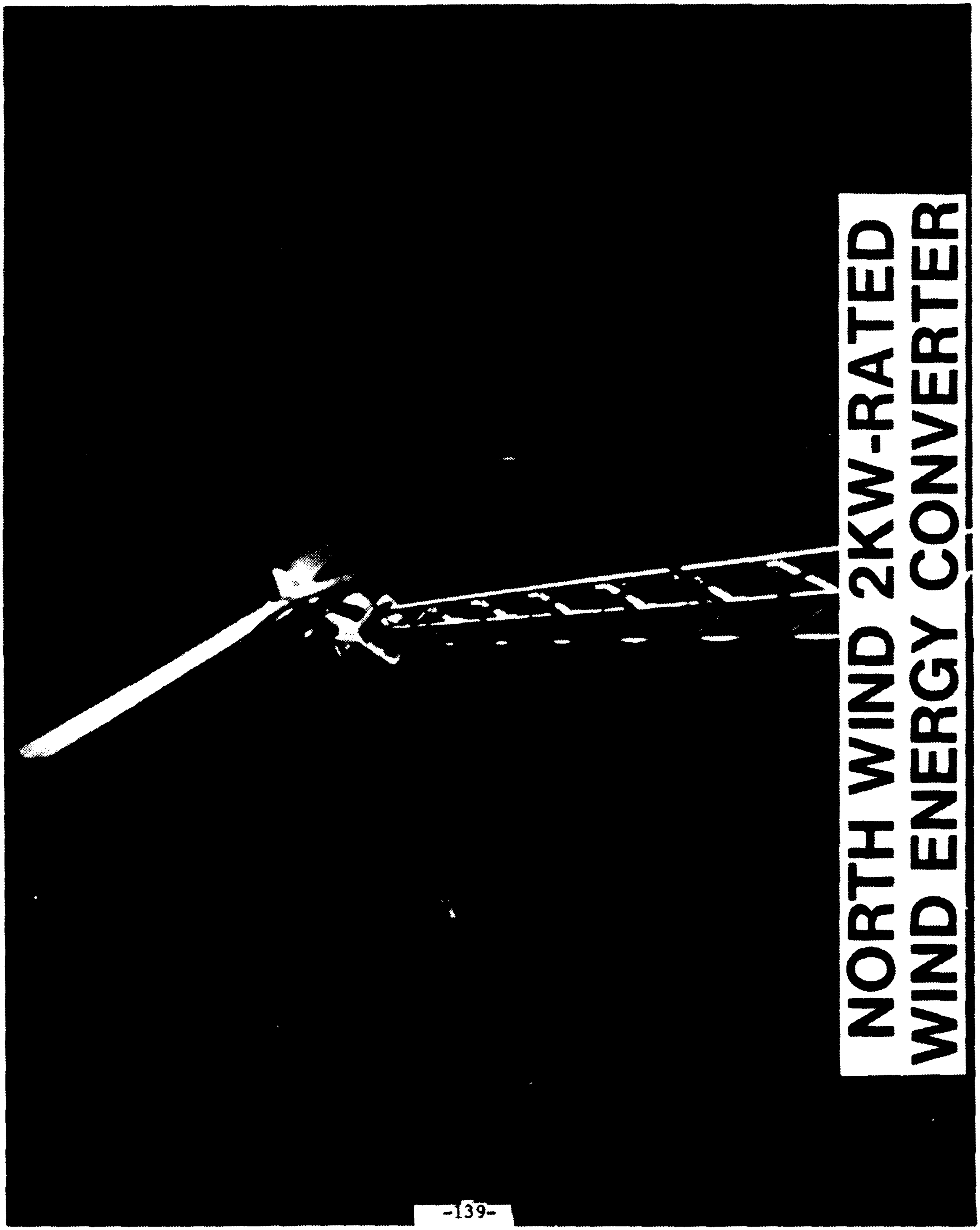
- ANALYZE THE PERFORMANCE OF THE BATTERY ARRAY
  - DEVELOP A COMPREHENSIVE BATTERY MODEL TO DEFINE RELATIONSHIP BETWEEN BATTERY VOLTAGE AND BATTERY CHARGE STATE
- VERIFY THE COMPUTER MODEL PREDICTING MINIMUM INITIAL CAPITAL COST WITH A GIVEN ELECTRICAL LOAD
  - MEASUREMENT OF BATTERY "DOWNTIME" UNDER A CONSTANT OUTPUT LOAD WITH ACTUAL WEC AND SOLAR PHOTOVOLTAIC POWER INPUT

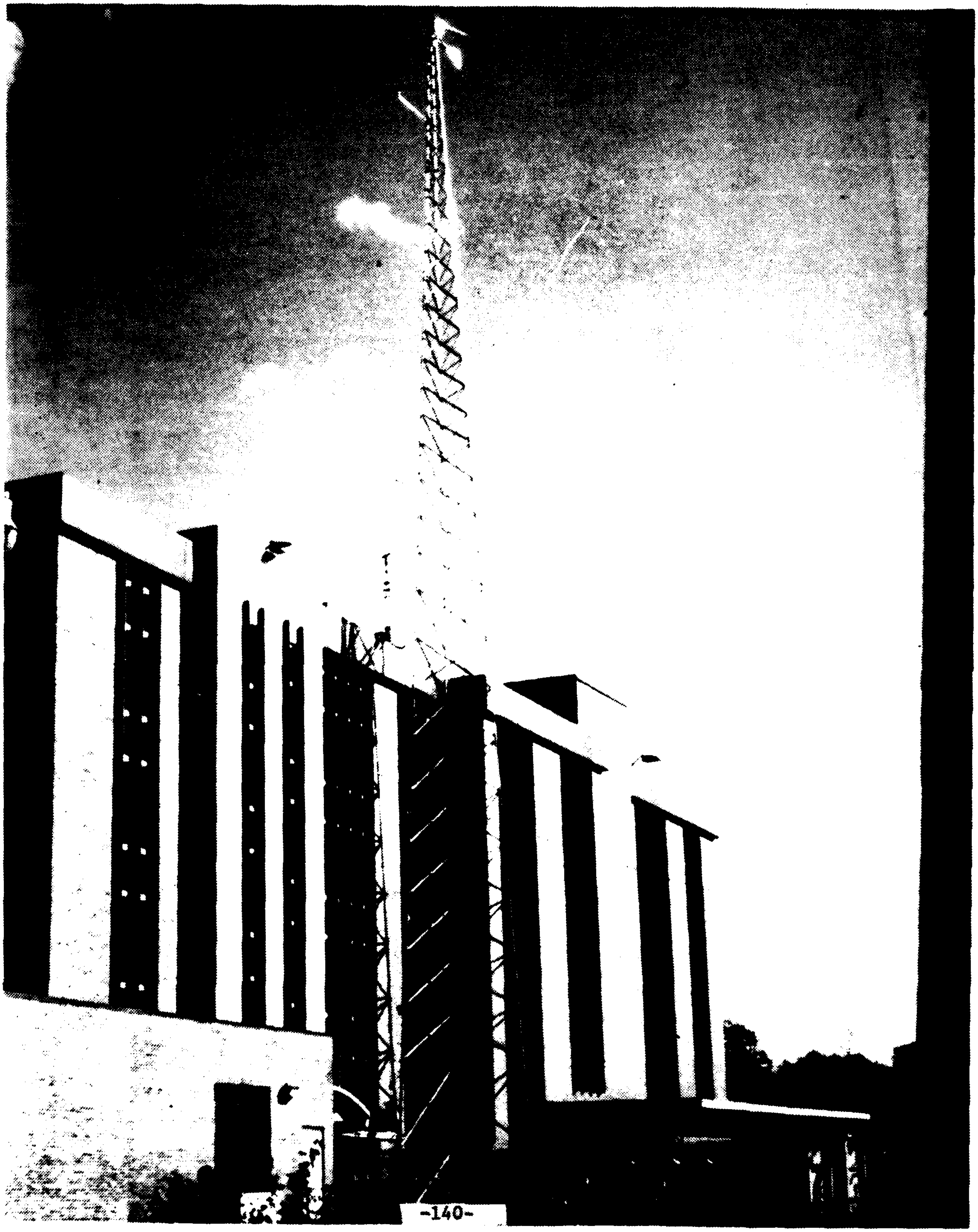
SYSTEM COMPONENTS

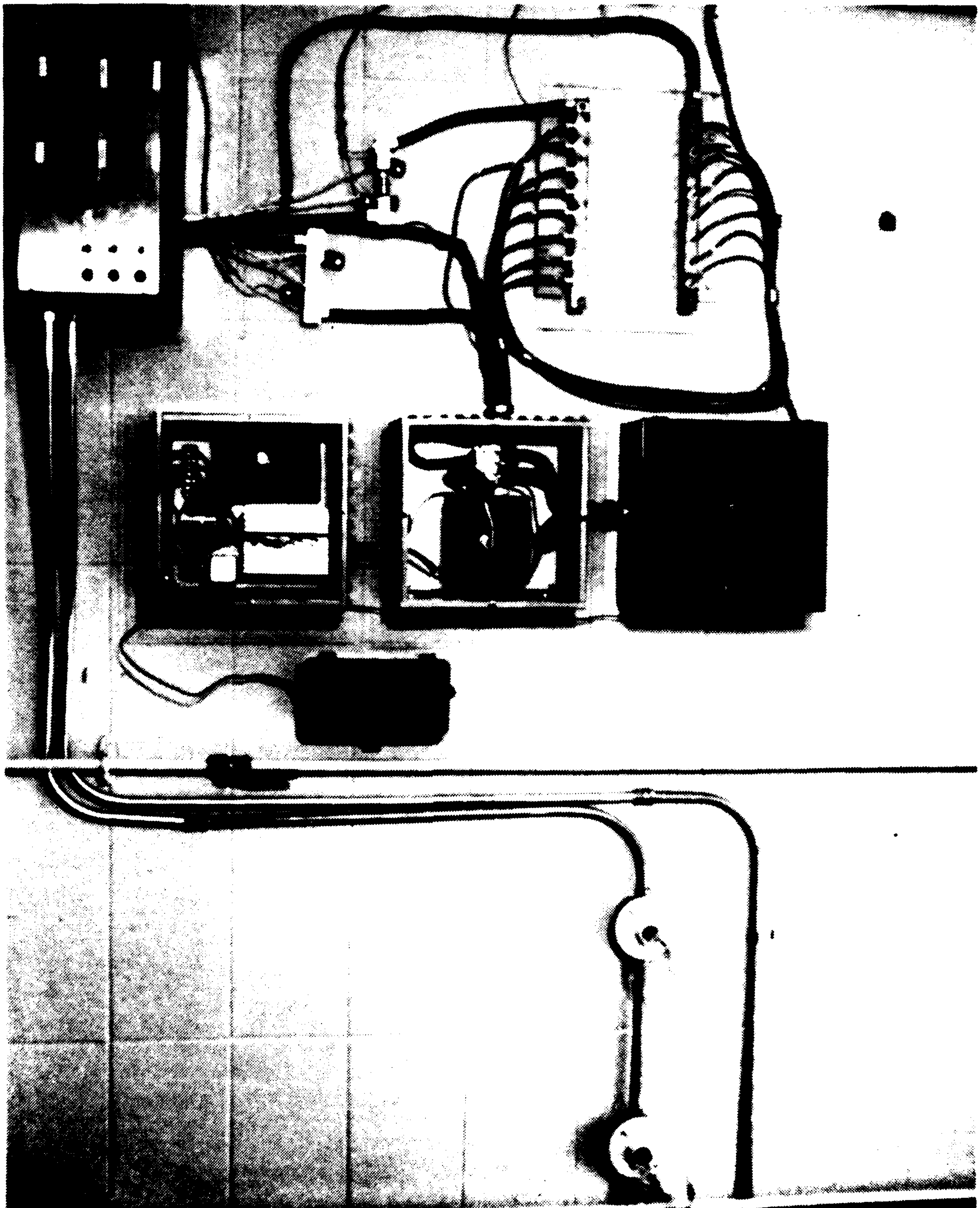
- 2 KW RATED WIND ENERGY CONVERTER
- 0.5 PEAK KW SOLAR PHOTOVOLTAIC ARRAY
- 36 KWHR BATTERY STORAGE
- 1 KW INVERTER
- 5 KW POWER SUPPLY
- COMPUTER DATA ACQUISITION SYSTEM

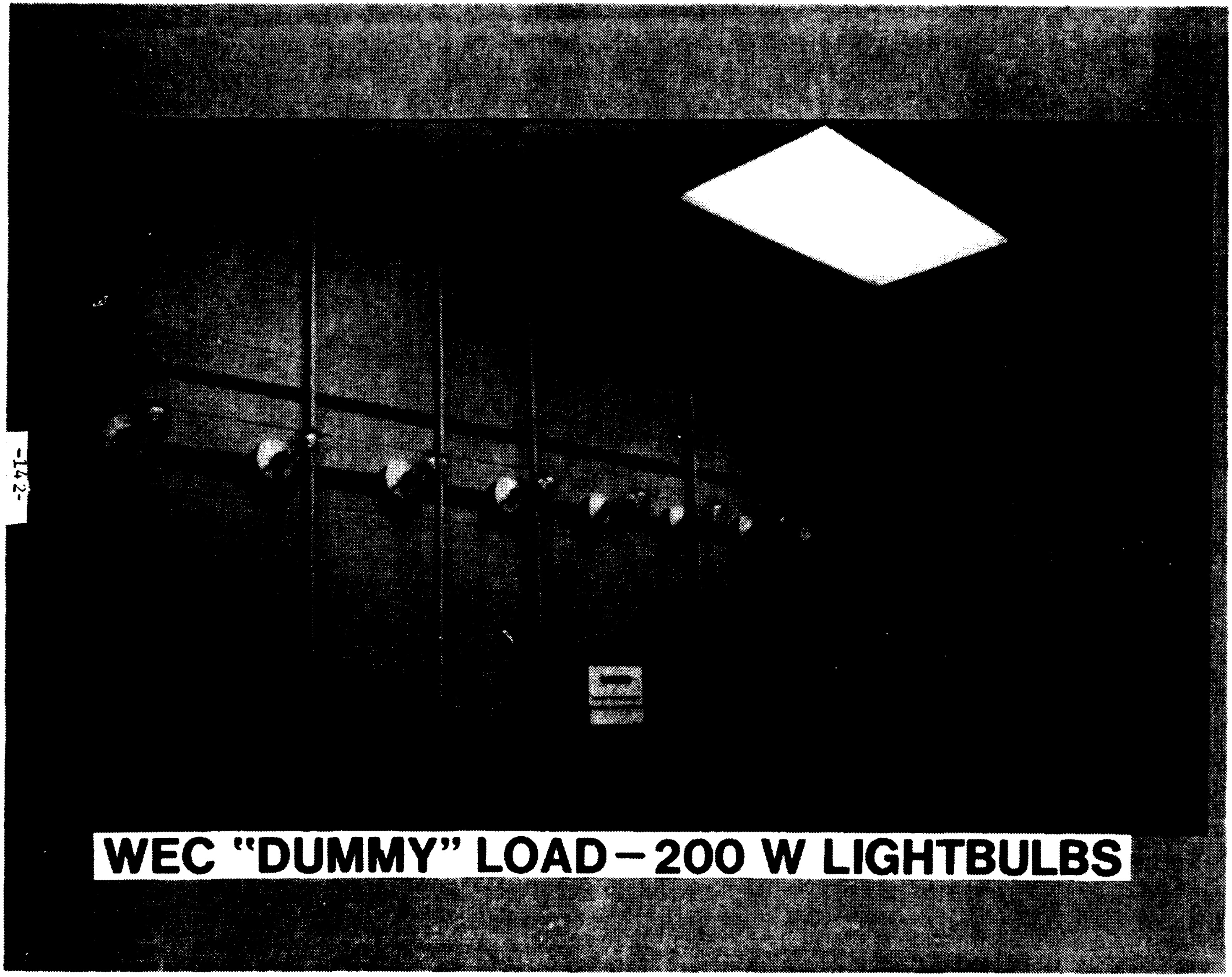
POWER SYSTEM SCHEMATIC




NORTH WIND 2KW-RATED
WIND ENERGY CONVERTER





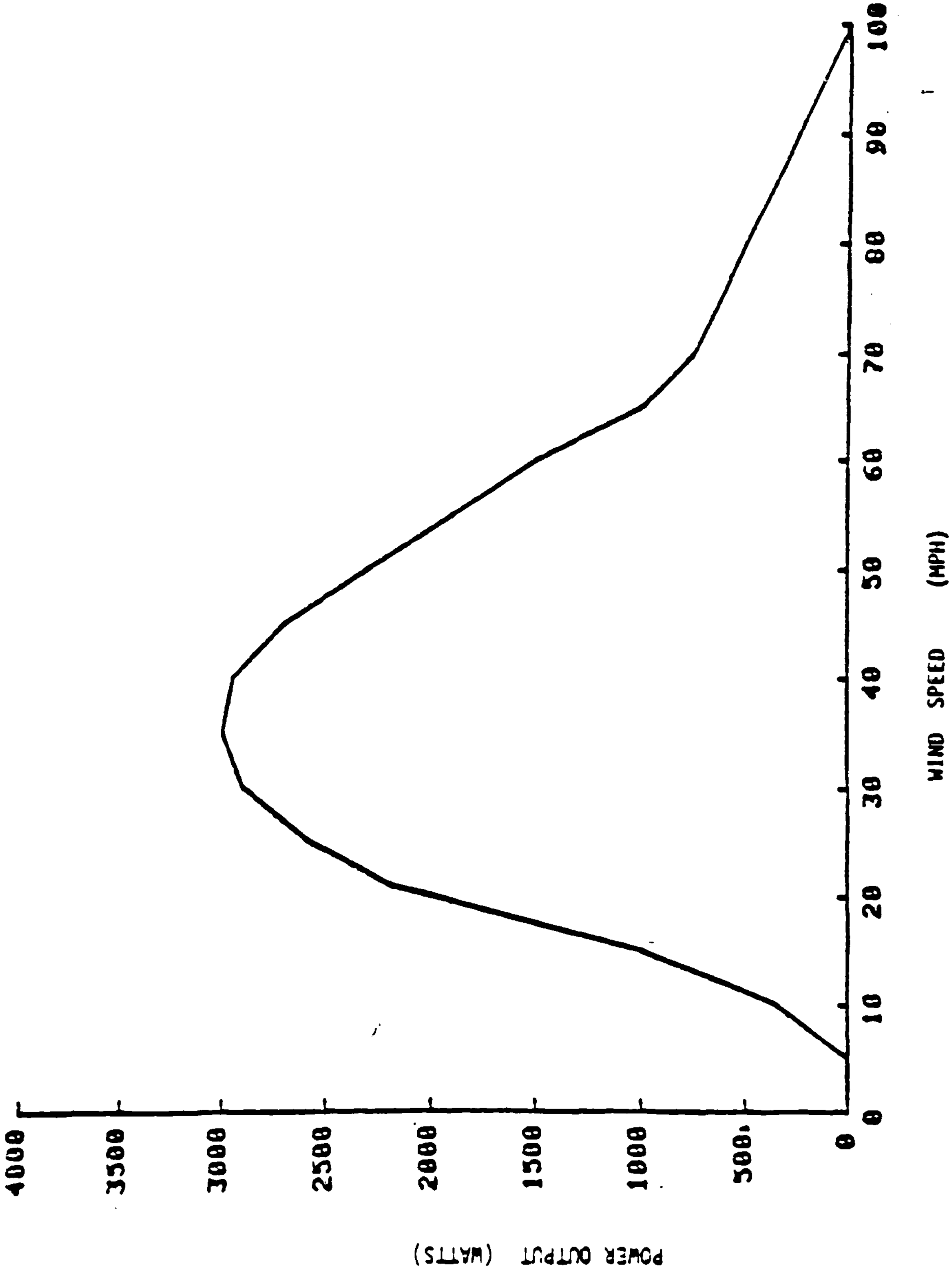


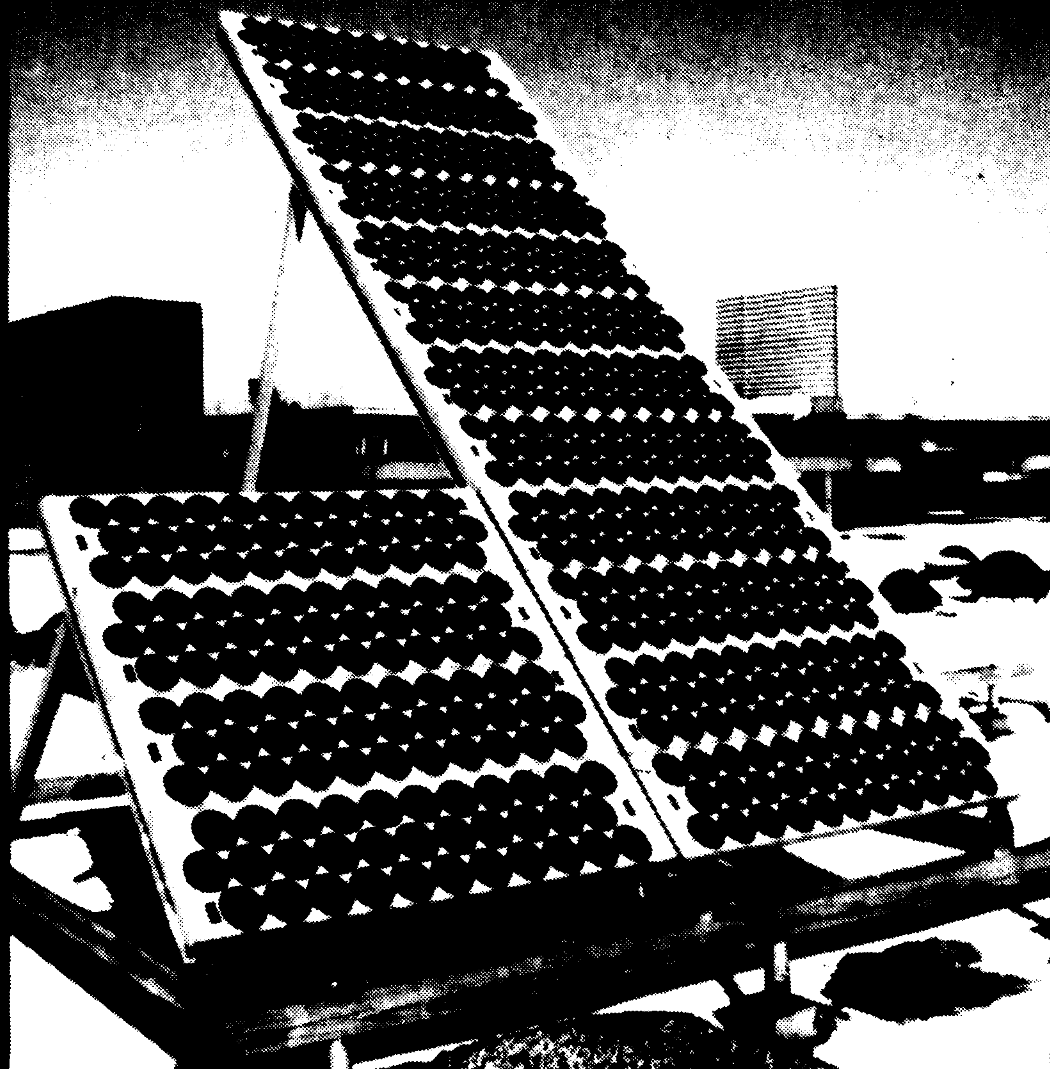
WEC "DUMMY" LOAD — 200 W LIGHTBULBS

NORTH WIND HR 2 WIND ENERGY CONVERTER

• NOMINAL VOLTAGE	32V DC
• RATED POWER OUTPUT	2200 WATTS AT 20MPH
• ROTOR CONFIGURATION	3 BLADED, HORIZONTAL AXIS, UPWIND
• SYSTEM WEIGHT	785 LB
• TOWER HEIGHT	160 FT
• TOWER WEIGHT	7190 LB
• ROTOR DIAMETER	16.4 FT
• BLADE MATERIAL	WOOD COMPOSITE
• CUT-IN WIND SPEED	8 MPH
• RATED WIND SPEED	20 MPH
• SPEED CONTROL INITIATION	21 MPH
• SYSTEM SHUTDOWN	105 MPH
• MAXIMUM AXIAL THRUST	630 LB
• OVERSPEED CONTROL	VARIABLE AXIS ROTOR CONTROL SYSTEM
• GENERATOR TYPE	3-PHASE, SYNCHRONOUS ALTERNATOR WITH WOUND STATOR
• FIELD CONFIGURATION	LUNDEL TYPE, SHUNT CONNECTED
• MAXIMUM POWER OUTPUT	3000 WATTS
• RECTIFICATION	SILICON DIODE FULL WAVE BRIDGE
• VOLTAGE REGULATION AND BATTERY PROTECTION	SOLID STATE FIELD CONTROL WITH OVER VOLTAGE PROTECTION

WIND GENERATOR CHARACTERISTICS



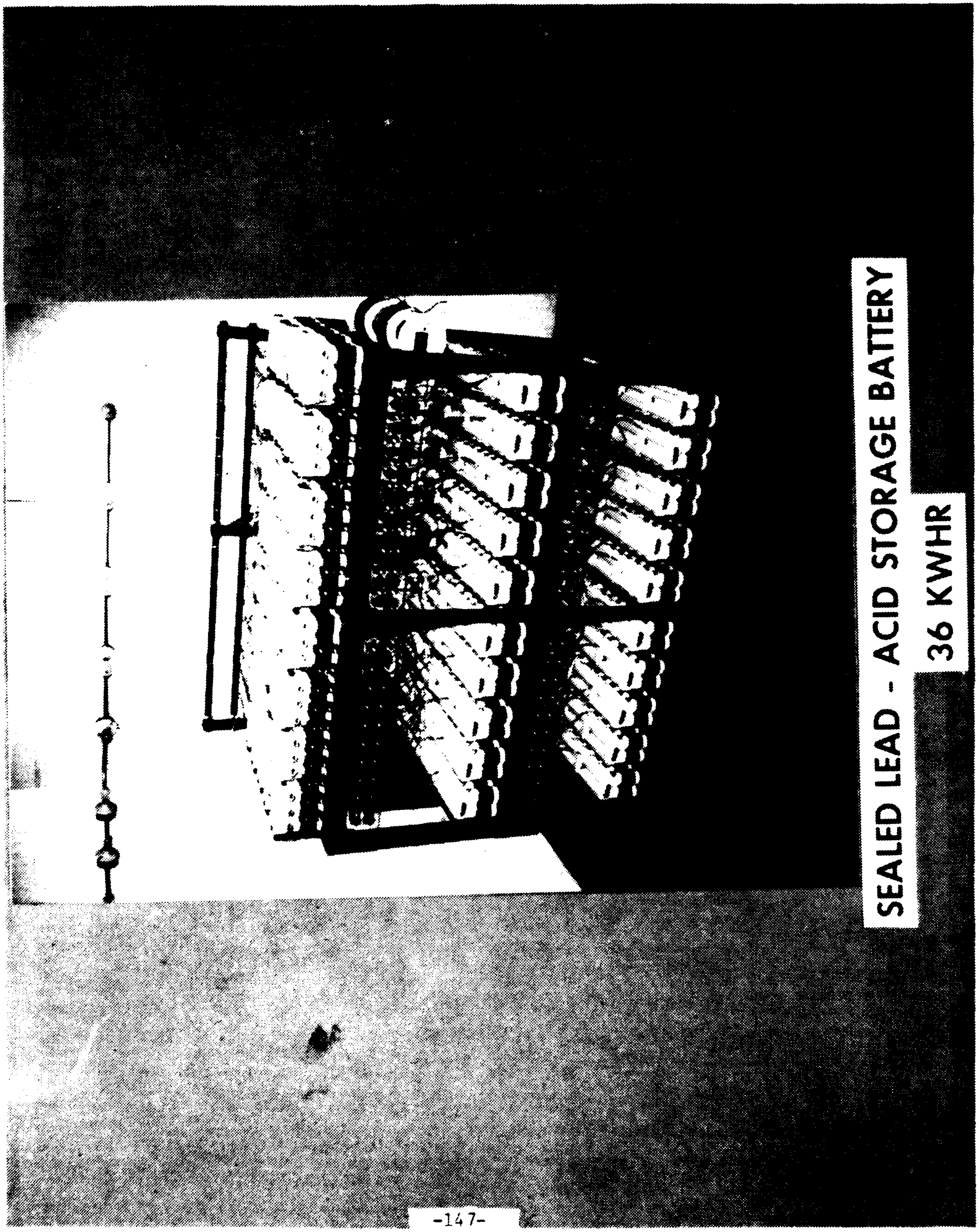


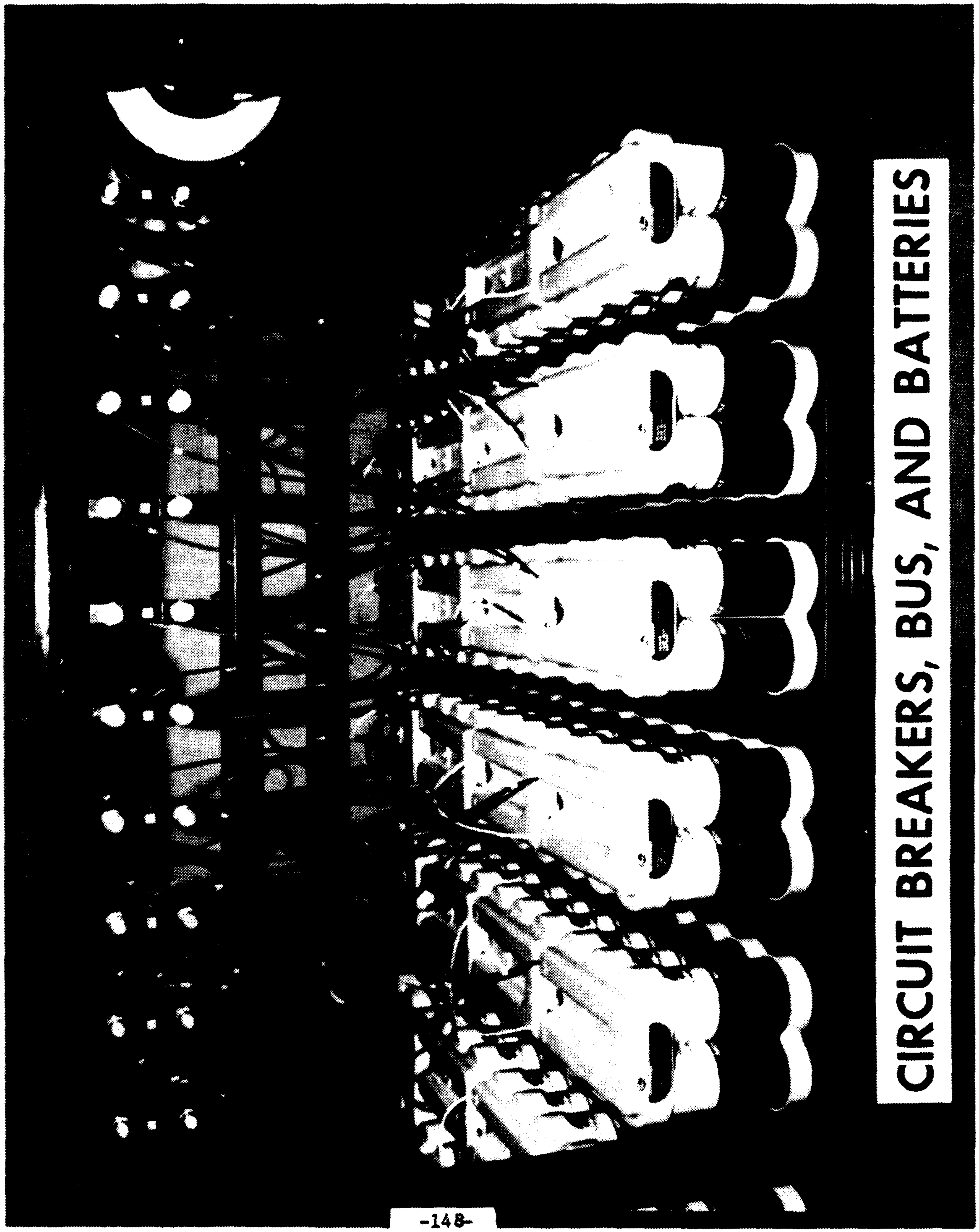
16 ARCO SSS SERIES SOLAR PHOTOVOLTAIC PANEL ARRAY

16 ARCO SSS SERIES SOLAR PHOTOVOLTAIC PANELS

- CIRCLE DIAMETER — 4 IN
- CONFIGURATION — 35 CIRCLES IN SERIES PER PANEL
- PANEL
  - LENGTH — 47.91 IN
  - WIDTH — 11.94 IN
  - DEPTH — 1.5 IN
  - WEIGHT — 10 LB
- PANEL PERFORMANCE AT 28C AND 1 SUN (100 mW/CM^2)
  - OPEN CIRCUIT VOLTAGE — 19.3 VOLTS
  - SHORT CIRCUIT CURRENT — 2.5 AMP
  - VOLTAGE AT PEAK POWER — 16.1 VOLTS
  - CURRENT AT PEAK POWER — 2.05 AMP
  - WATTS AT PEAK POWER — 33 WATTS

- LABORATORY CONFIGURATION — 2 PANELS IN SERIES; 8 SETS OF PANELS IN PARALLEL
  - VOLTAGE AT PEAK POWER — 32.2 VOLTS
  - CURRENT AT PEAK POWER — 16.4 AMP
  - WATTS AT PEAK POWER — 500 WATTS

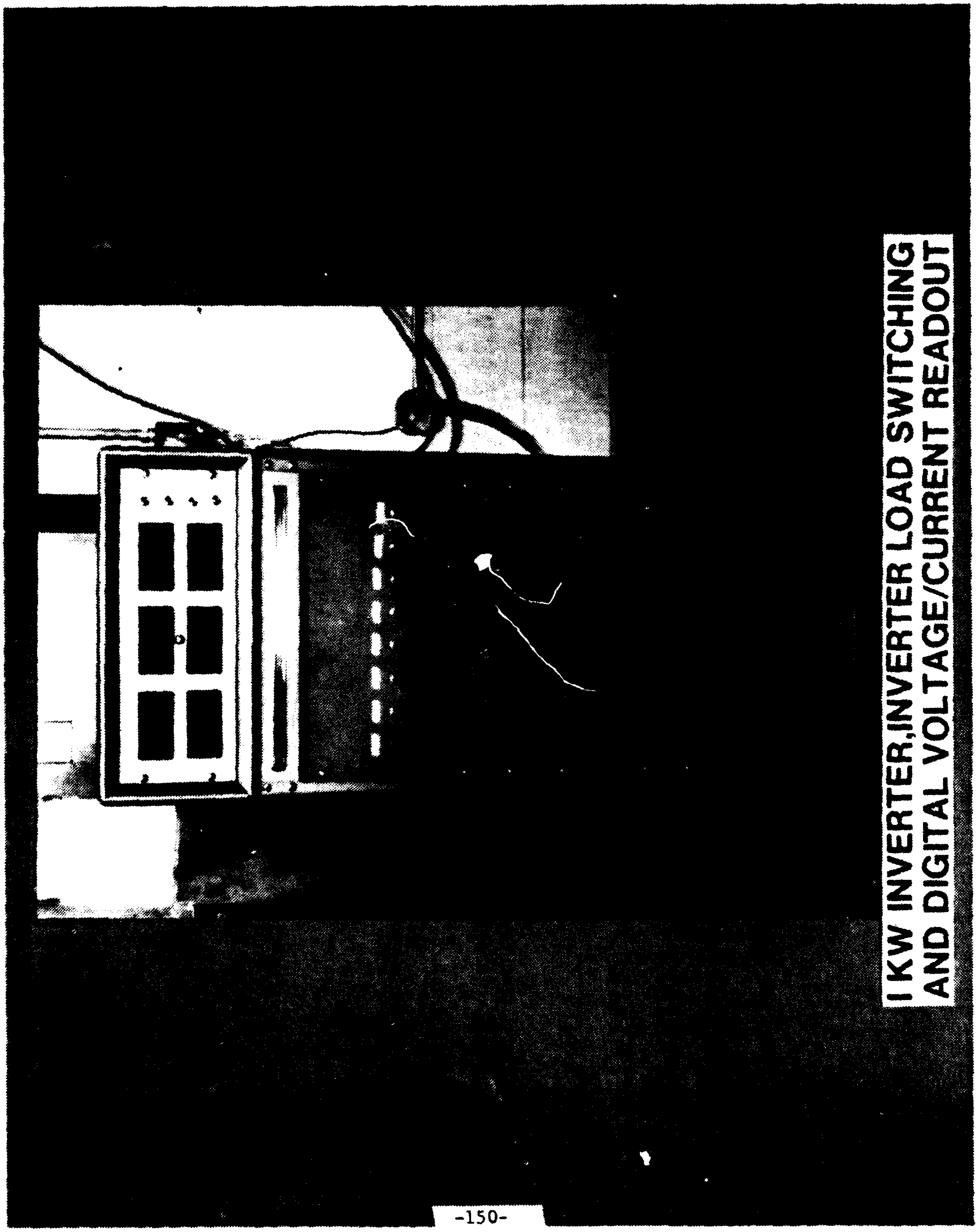

SEALED LEAD - ACID STORAGE BATTERY
36 KWHR

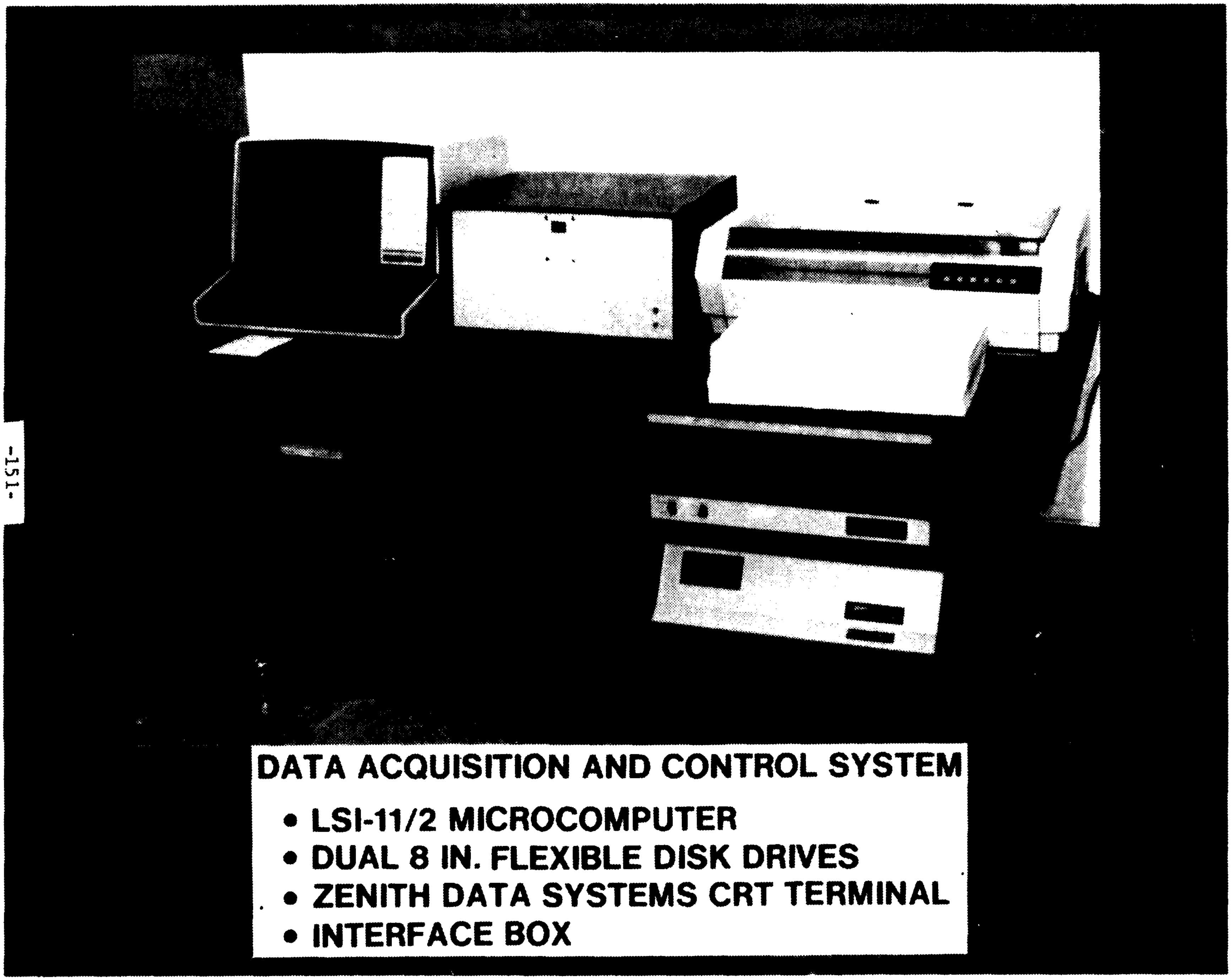


CIRCUIT BREAKERS, BUS, AND BATTERIES

720 GATES ENERGY PRODUCTS SEALED LEAD-ACID RECHARGEABLE BC CELLS

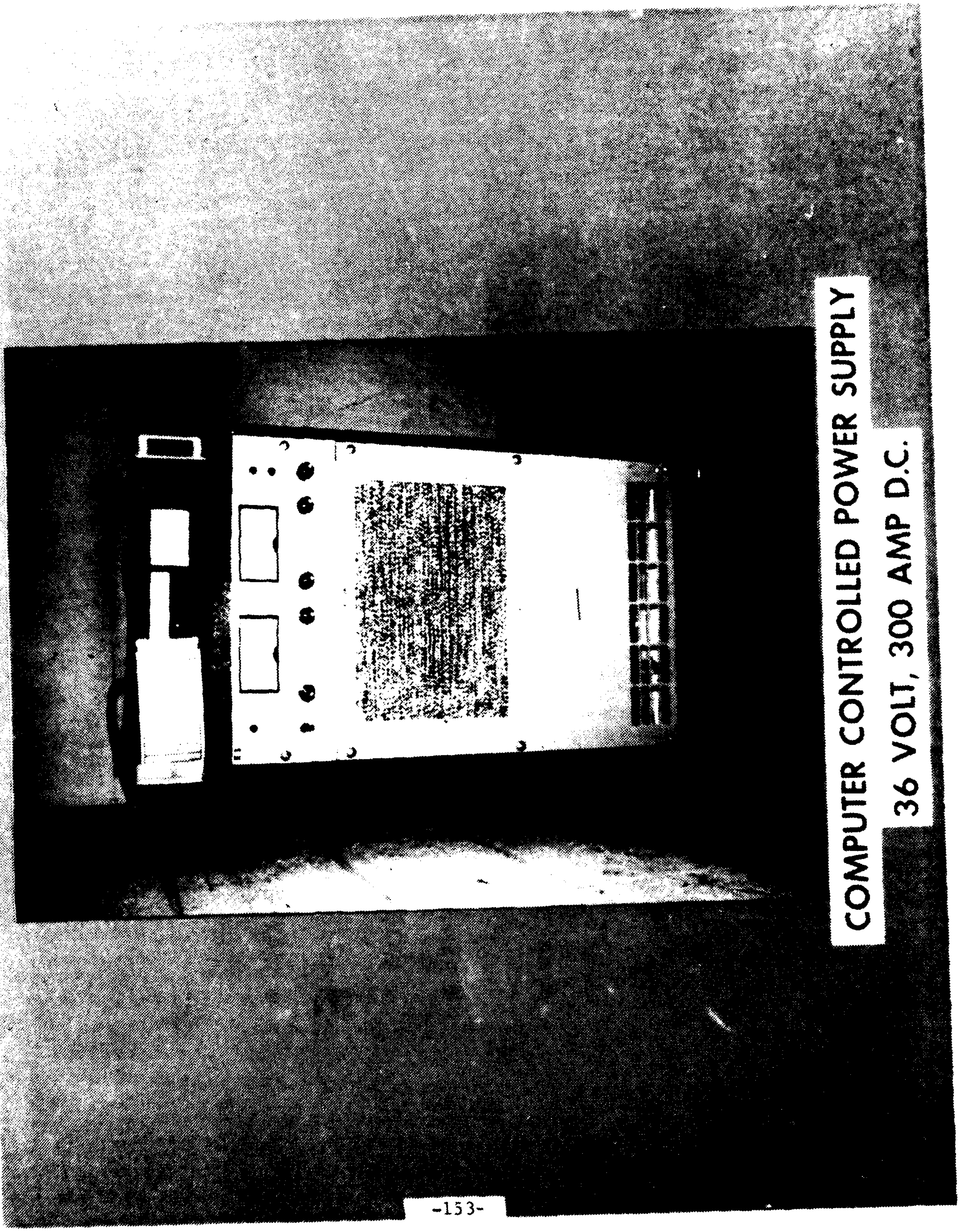
• NOMINAL CELL VOLTAGES	2 VOLTS
• NOMINAL AMPERE HOURS	25 AMPERE HOURS
• CYCLE LIFE	200-2000 CYCLES
• ESTIMATED FLOAT LIFE	8 YEARS
• SAFETY	NO PROBLEMS WITH THERMAL RUNAWAY CAUSED BY OVERCHARGING
• CONFIGURATION	SAME SIZE AS 16 OZ BEER CAN
• LABORATORY CONFIGURATION	12 CELLS IN SERIES 60 BATTERIES CONNECTED IN PARALLEL TO FLOATING BUS
• BATTERY CAPACITY (NOMINAL)	36 KWHR
• BATTERY/CONVERTER VOLTAGE (NOMINAL)	28 V DC
• BATTERY/CONVERTER VOLTAGE (OPERATING RANGE)	22 V DC - 32 V DC


I KW INVERTER,INVERTER LOAD SWITCHING
AND DIGITAL VOLTAGE/CURRENT READOUT


DATA ACQUISITION AND CONTROL SYSTEM
• LSI-11/2 MICROCOMPUTER
• DUAL 8 IN. FLEXIBLE DISK DRIVES
• ZENITH DATA SYSTEMS CRT TERMINAL
• INTERFACE BOX

DATA ACQUISITION SYSTEM

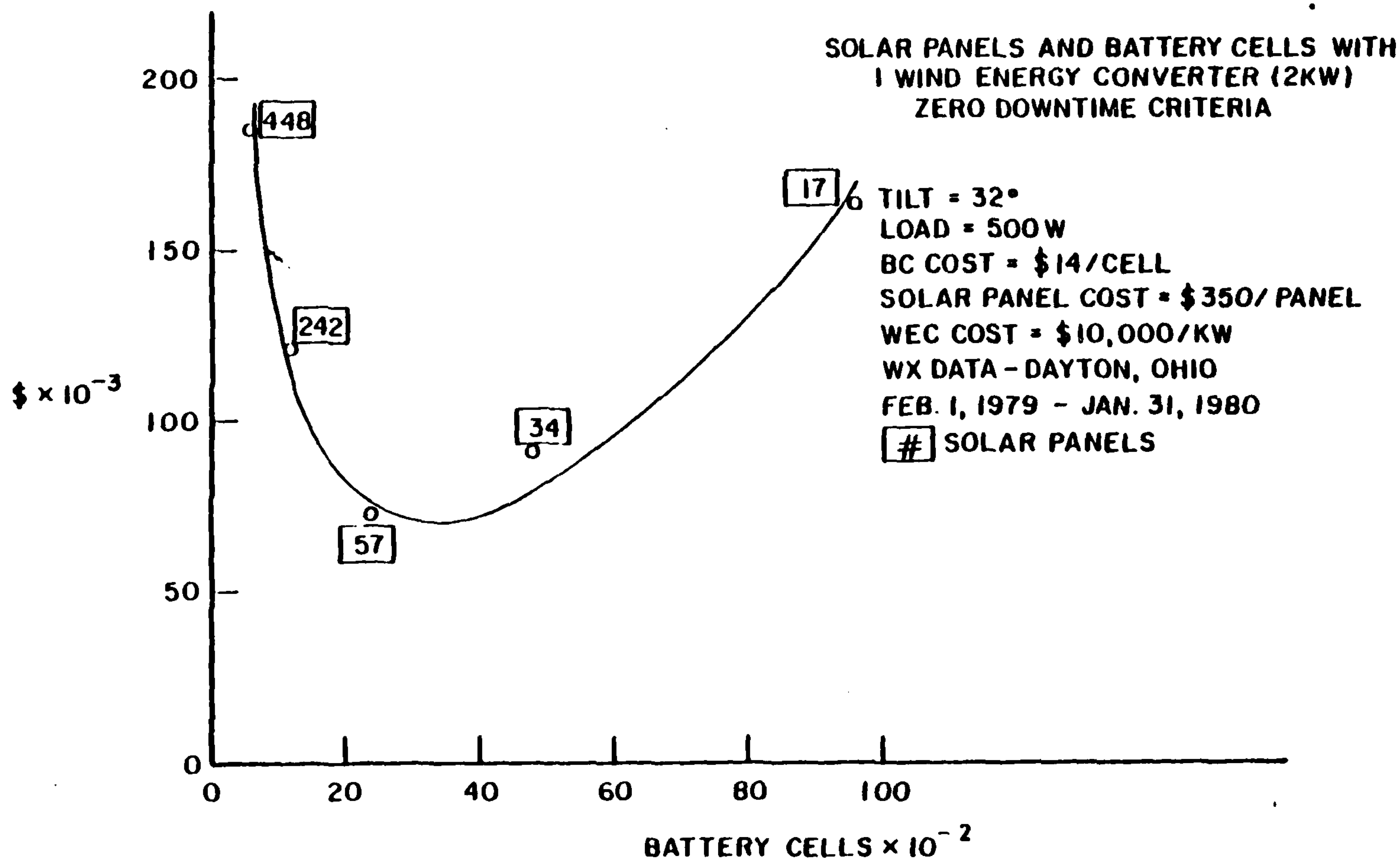
- DIGITAL EQUIPMENT CORPORATION (DEC) LSI-11/2 16-BIT MICROCOMPUTER
- 16 CHANNELS OF 12-BIT A/D
- 2 CHANNELS OF 12-BIT D/A
- 64 BITS OF PARALLEL I/O
- PROGRAMMABLE REAL-TIME CLOCK
- 512 K BYTES OF FLEXIBLE DISK STORAGE
- INTERFACE BOX WITH 64 CHANNEL MULTIPLEXER
- DATA UPDATE EVERY 15 SECONDS
- AUTOMATIC TRANSFER OF DATA FILES TO VAX-11/780 MINICOMPUTER
- PRESENTS REAL-TIME INFORMATION ON:
    - 60 BATTERY PACK VOLTAGES
    - WEC VOLTAGE AND CURRENT
    - SOLAR PANEL VOLTAGE AND CURRENT
    - WINDSPEED
    - TOTAL SOLAR INTENSITY
    - AMBIENT TEMPERATURE NEAR SOLAR PANELS
    - INVERTER INPUT VOLTAGE AND CURRENT
    - INVERTER OUTPUT VOLTAGE AND CURRENT
    - TOTAL BATTERY ARRAY INPUT BUS VOLTAGE AND CURRENT



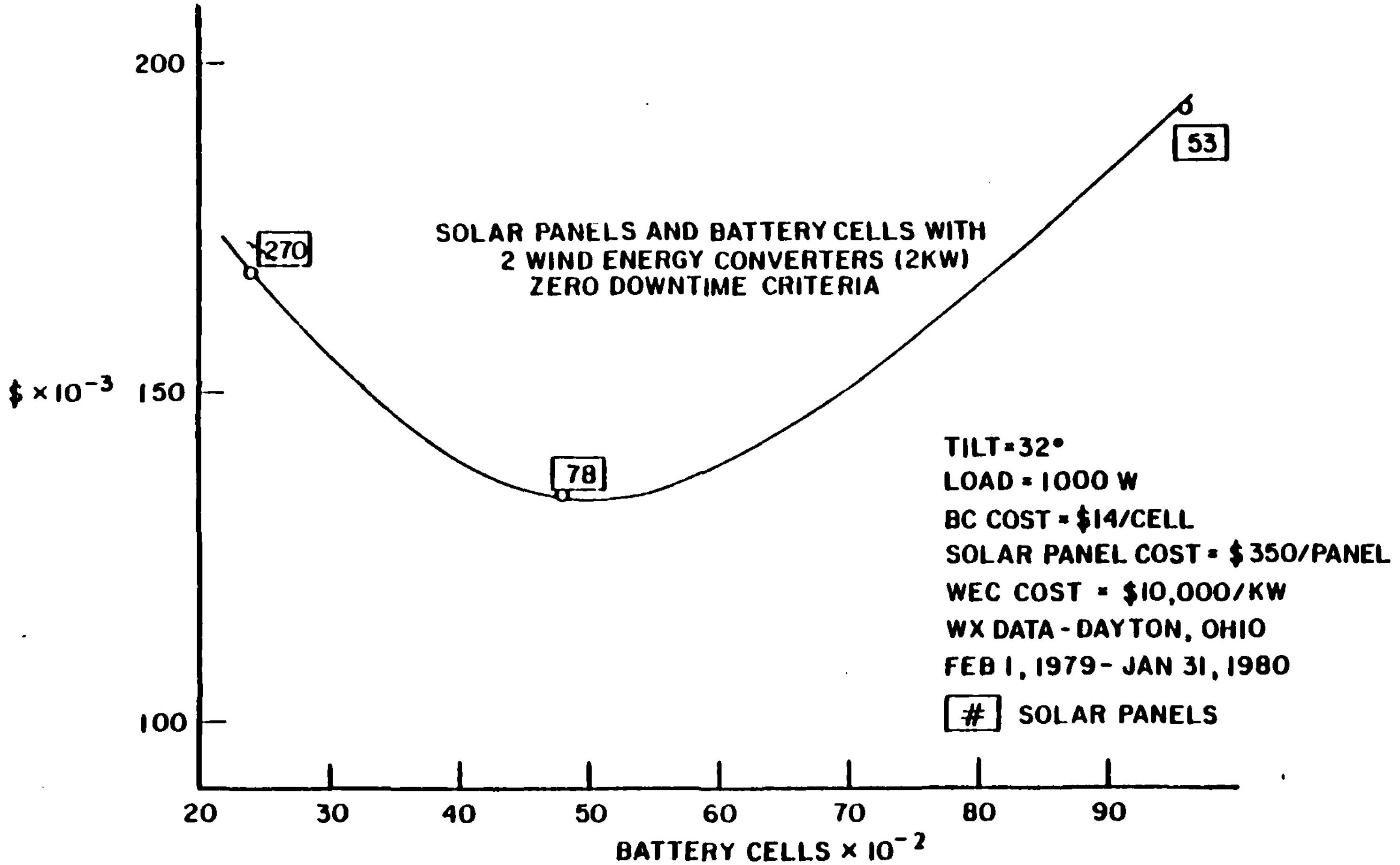
COMPUTER CONTROLLED POWER SUPPLY
36 VOLT, 300 AMP D.C.

HEWLITT PACKARD 6469C
DIRECT CURRENT POWER SUPPLY

- **INPUT** — 208/230/380/400/460 V AC, THREE PHASE, 57 TO 63 Hz, 50A/PHASE @ 230 V AC
- **OUTPUT** — 0 - 36 V DC @ 0-300A
- **WEIGHT** — 500 LBS
- **SIZE** — 16 3/4" W x 26 1/4" H x 26 1/8" D
- **MAXIMUM OUTPUT CAPABILITY** — 9.75 KW



Optimized Initial Cost - 500 W Load



Optimized Initial Cost - 1000 W Load

STATUS

- SYSTEM OPERATIONAL (2 KW WIND, 1/2 KW SOLAR)
- PERFORMANCE MODEL COMPLETED
- SIZING MODEL IN PREPARATION (AVAILABLE APRIL 1983)
- NEED ADDITIONAL 4 1/2 KW SOLAR (75 K)
- WORK WILL TERMINATE OCTOBER, 1982
- NO STRONG USER INTEREST OR SUPPORT

SUMMARY

- WIND AND PHOTOVOLTAIC HYBRID STAND ALONE DEMONSTRATION FACILITY IS OPERATIONAL
- CAN OPERATE IN THREE MODES: WIND ONLY, PHOTOVOLTAIC ONLY, OR COMBINED
- SYSTEM IS MODELED AND IS FLEXIBLE
- HYBRID SYSTEM SMOOTHES SEASONAL VARIATIONS IN AVAILABLE POWER OUTPUT
- MINIMUM COST SYSTEM CAN BE ACHIEVED
- CAPABLE OF LONG TERM UNATTENDED/LOW MAINTENANCE OPERATION WITH LITTLE, IF ANY, DOWN TIME

ECD WIND MACHINE INSTALLATION

THOMAS C. HARDY

A Machinewerk-Augsburg-Neurnberg (MAN) prototype wind generator installed at Bann main site, located less than 10 miles south of Ramstein AB, GE, is designated an operating location of the communications detachment at Langerkopf. The parent organization for both units is the 1945th CG at Rhein Main.

Both the wind generator and commercial power are alternating current. The two sources are fed through a transformer and rectifier reducing the voltage and changing it from AC to DC. At this point the prioritizing circuit comes into play. This circuit is designed to select the supplied voltage as long as its rectifier is producing approximately 56 volts. The voltage is available when there is at least an 8-mile-an-hour wind. When the wind slows enough to reduce the voltage below 54 volts, the circuit selects commercial power as its source for battery charging to power microwave equipment. The wind machine's instrumentation battery is charged by solar cells. This battery supplies power for an anemometer and a meter that records wind data.

The wind generator requires very little maintenance. It needs quarterly inspections to look for unusual wear and an annual lubrication (oil and grease). The life expectancy of the generator is 20 years. The written specifications for this project are included as a handout for this presentation.

September 1980

PERFORMANCE SPECIFICATIONS FOR
WIND POWER GENERATOR SYSTEM
BANN MAIN SITE

EIN 80-0578

UNITED STATES AIR FORCES IN EUROPE

PERFORMANCE SPECIFICATIONS

I. Preliminary Remarks

1. SCOPE: These specifications outline the minimum performance requirements for construction of a wind power generator at the US Communication Station "Bann Main Site", on the left-hand side of the road between Landstuhl and Weselberg-Zeselberg.

2. MINIMUM REQUIREMENTS: The proposed installation shall meet the following requirements:

   a. APPLICABLE STANDARDS:
      Concrete Work, DIN 1045
      Statical Loads for Structures and Buildings
      Electrical Work, VDE 0100, 0190, 0510, 0660
      Accident Prevention Standards of the German Construction Trade Association
      Lightning Protection - ABB, DIN 18 384

   All references to other publications identified or referred to in all of the publications listed in 2.a. above are part of the requirements for this installation.
   In accordance with VOB, part A, para. 20.2.1 the preparation of an offer will not be compensated.

   b. TYPE OF CONSTRUCTION:
      Steel lattice mast, hot galvanized, or reinforced concrete mast with concrete foundation, with the wind power generator installed on top, with a life expectancy of 20 years at normal maintenance.
      Recommended mast height: 15 m Minimum/25 m Maximum
      The entire installation shall comply with the latest standards of technique and shall withstand a wind velocity of 160 km/hr.

   c. OVERALL MATERIAL, EQUIPMENT AND APPURTENANCE REQUIRMENTS:
      All materials, equipment and appurtenances must be designed and manufactured for commercial use by companies regularly manufacturing or producing the materials and/or equipment, and must be suitable for the use intended and the life expectancy specified in para. b. The Contracting Officer reserves the right to reject submission of materials and/or equipment as not meeting the quality standards required by the specified life expectancy. Each piece of equipment shall carry the normal commercial warranty but not less than a period of 2 years.

3. a. TECHNICAL DATA OF THE GENERATOR:
Standard generator, three-phase current, synchronous, protection mode IP 54, approximate capacity 15 - 25 KVA, voltage 380/220 V ± 5%, frequency 50 Hz ± 5%. Transmission of electrical power down to the mast base.

b. MECHANICAL DRIVE:
Rotor with automatic blade adjustment, capable of maintaining speed within ± 5% and overspeed protection. Rotor blades shall have a 20 year life expectancy with normal maintenance. Normal output: 9 m/sec.

c. FOUNDATION:
Foundation, to include excavation, shall be constructed according to the supplier's recommendation for maximum wind load, in soil class 6.

d. WIND CONDITIONS IN THE AREA OF INSTALLATION:
For determination of an optimum wind generator efficiency, a list of the annual wind conditions at the place of installation is attached to these specifications.

e. OPERATING AND MAINTENANCE INSTRUCTIONS:
Operating and maintenance instructions, assembly drawings, wiring diagrams, parts lists, and test certificates, in triplicate, German and English, shall be handed over to the Contracting Officer during final acceptance.

4. LIST OF DRAWINGS AND OTHER ATTACHMENTS:

a. One drawing, layout and wiring diagram 1 of 1
b. Wind speed graphs 1 of 1

5. LIST OF SUBMITTALS:

Items	Description	Type of Submittal
2. b	Mast	Construction drwg.
3. a	Generator	Manual or catalog
3. b	Mechanical drive	Manual or construction drwg.
2. 15	Anemograph	Catalog

II - Electrical Work

Item	Description of Additional Electrical Work
2.01	Sheet steel distribution cabinet, with protective insulation, type for surface-mounting, two-wing door with locking handle, equipped with the following gear:

1 ea isolating circuit breaker, 3-pole, 40 Amps;
1 ea fuse cut-out switch, NH 00,100/35 Amps, 3-pole, including fuse;
1 ea NEOZED-type fuse, 25/6 Amps, 3-pole, including fuse;
6 ea automatic circuit breakers, 25 Amps, 3-pole, type G;
3 ea ammeters, indicating range 0-40 Amps, moving-iron measuring device, class 1.5, dimensions of front side 72 x 72 mm;
1 ea Voltmeter, indicating range 0-500 V, moving-iron measuring device, class 1.5, dimensions of front side 72 x 72 mm;
1 ea frequency meter, indicating range 45-55 Hz, vibration movement, accuracy ± 0.5% of the rated value at nominal frequency, 50 Hz, dimensions of front side 72 x 72 mm, voltage 380 V, 1 ea working hour meter 220 V, 50 Hz;
1 ea voltmeter change-over switch, three phase phase-to-phase voltage with neutral position;
1 ea three-phase watt-hour meter (uncertified), four-wire system, for direct connection, single tariff-rate, 3 x 380/220 V, 400% rated current 10 (40) Amps, PE and N bar, terminal strip,
factory wired
12 ea Pg glands size 16 on top,
1 ea Pg gland size 29 at the bottom;

identification of circuits and control units as shown on the drawing.
Identification of distribution unit with formica sign fastened to the outside of the door, white letters on a black ground, height of characters 30 and/or 8 mm
"WIND POWER GENERATOR PANEL"
"380/220 V 50 Hz"

Item	Description of Work
2.02	Three-phase watt-hour meter (uncertified) for four-wire system and direct connection, single tariff-rate, 3 x 380/220 V 400% rated current 15 (60) Amps, in a plastic housing with transparent cover, protection mode IP 54.
2.03	Existing molded plastic casing, with 4 ea 3-pole automatic circuit breakers, shall be altered as described below and as shown on the drawing: Rails for automatic circuit breakers shall be severed in their center, rectifier circuits shall be repositioned to the right side, feed line for automatic circuit breakers of rectifier shall be run via the electric meter, 2 ea glands Pg 21 shall be added, required cable: 3 m, NYM-J, 4 x 6 mm^2, on spacing clamps; incidental material; 4 ea 3-pole automatic circuit breakers, 25 A, G-type, and 4 ea glands Pg 16, shall be added, incl. fastening rail.
2.04	Molded plastic casing, protection mode IP 54, equipped with the following switchgears: 6 ea mains change-over switches, 3-pole, 25 Amps, as built-in switches, with actuating device on the outside, dial plate, terminal strip on top and at the bottom (36-pole on top, 18-pole at the bottom), Pg glands 21, 12 ea on top, 6 ea at the bottom, PE and N bar.
2.05	Existing cables, 2 ea, 5 x 2.5 mm^2 (rectifier circuits) shall be removed from the existing molded plastic casing, and inserted into the new housing with the change-over switches.
2.06	Existing ground potential equalizing bar located beneath the molded plastic-encased distribution unit shall be removed and reinstalled laterally to the left. Required cable: 3 m, NYM, 1 x 25 mm^2.

Item	Description of Work
2.07	Cable, 45 m, NYCWY, 3 x 16 mm^2, round, single-core/16 mm^2, shall be installed in the cable trench. (Wind power generator - Bldg. # 9)
2.08	Cable, 18 m, NYCWY, 3 x 16 mm2, round, single-core/16 mm^2, shall be installed in a plastic cable raceway (inside bldg. # 9).
2.09	Strap steel, galvanized, 30 x 3.5 mm, 50 m, shall be installed in the cable trench and connected to the steel pole of the generator.
2.10	Cable,20 m, NYM-J, 5 x 2.5 mm2, shall be installed in a plastic conduit.
2.11	Cable, 28 m, NYCWY, 3 x 16 mm^2, round, single-core/16 mm^2, shall be installed in existing cable trough (inside bldg. # 9, new bldg.).
2.12	Cable trench, 40 x 70 cm, 45 m, soil class 4-5, shall be excavated by hand, 10 cm thick sand bed shall be applied and cable shall be placed therein and shall be covered with plastic cable cover tiles. The trench shall then be backfilled in layers and compacted, and the former surface condition shall be reconstructed. An identification tape shall be installed at half trench depth.
2.13	Steel conduit, galvanized, 3 m long, 36 mm, shall be installed on the outside of bldg. # 9, as protective cable conduit.
2.14	Plastic cable conduit, 4 m, height/width 45/67 mm, for installation of cables at boxes B, C, and D.

Item	Description of Work
2.15	Mechanical 60 day anemograph, "KAHLSICO No. 02 AM 300", of firm Kahl Scientific Instrument Corporation, P.O. Box 1166, El Cayon (San Diego), California 92022, for recording cumulative wind and direction, (10 km scale) complete with strip chart recorder, battery-rewound clockwork chart drive, set of three 1.5-volt flashlight batteries, nomograph and 5 chart rolls.

ACCESSORIES AND SPARE PARTS:

a. No. 32 AM 305 accessory post mounting bracket, suitable for attachment of the recorder housing to a threaded 2.5" pipe.

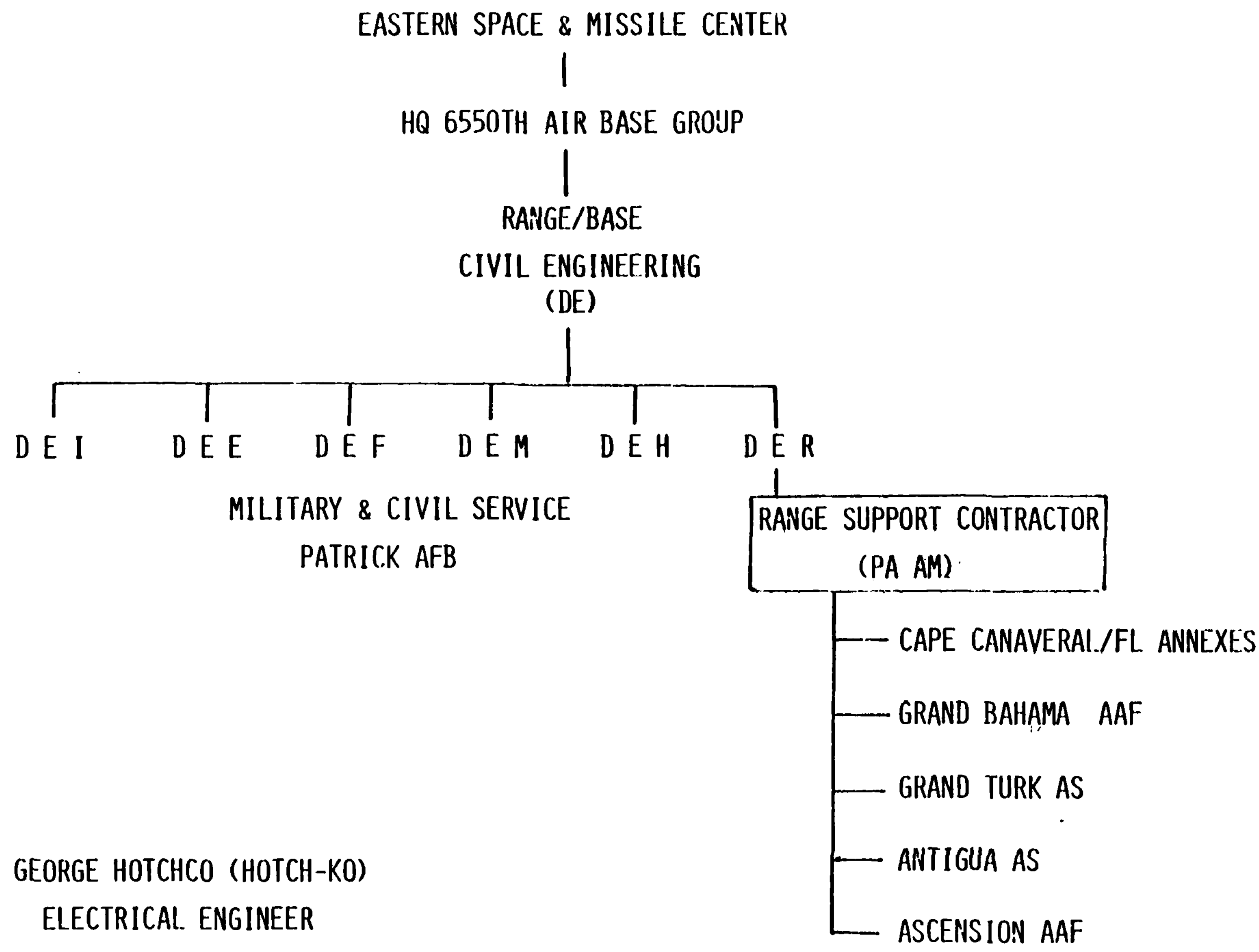
b. No. 40 AM 155 sturdy 2.5" diameter support pipe for the anemograph, 2 m (6.5 ft) high, with tripod base. Dismountable for transport and quick installation.

c. No. 02 AM 302 spare chart rolls, 10 km; set of 10. 5 sets = 50 ea.
Mounting location: On top of bldg. # 9.

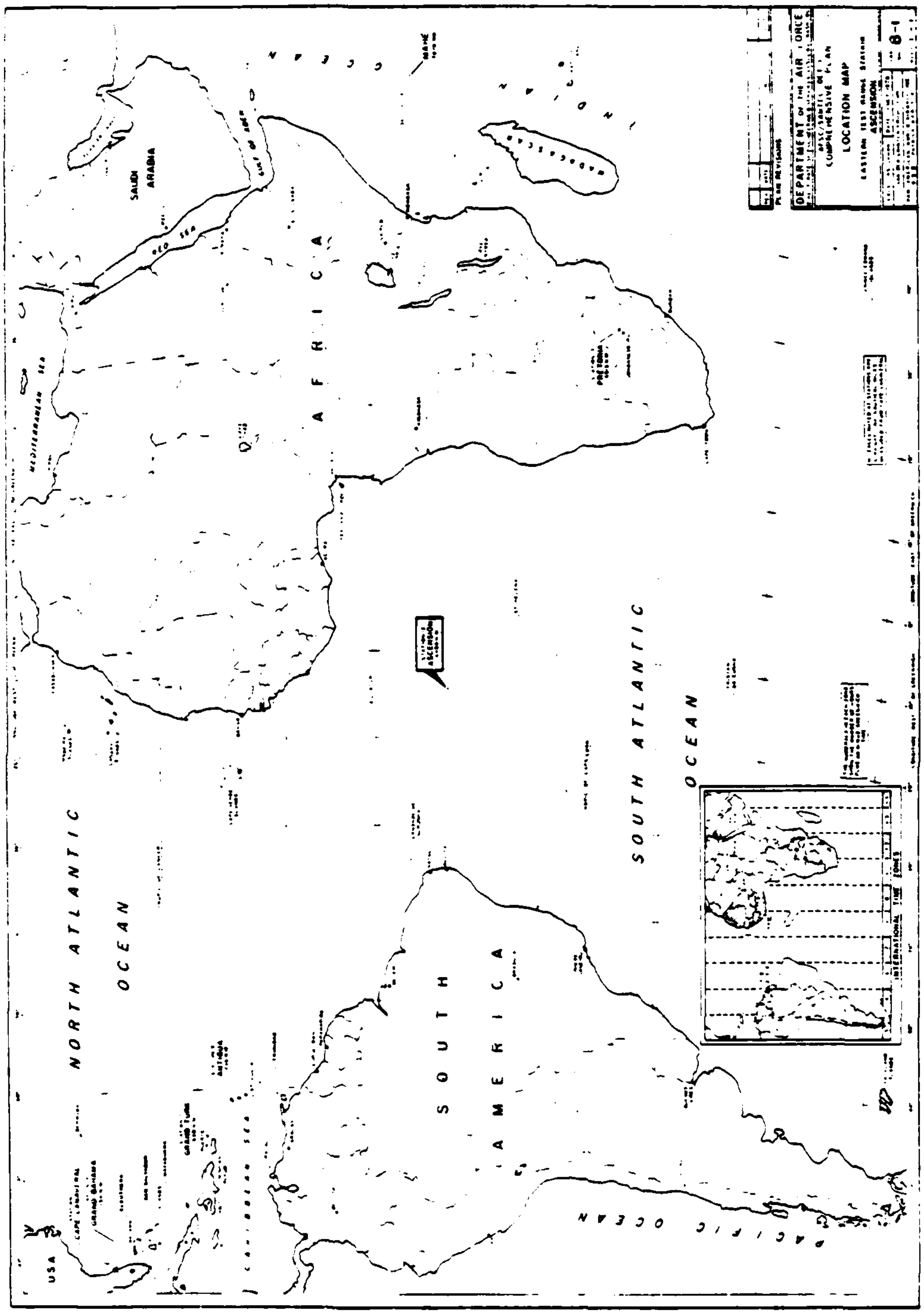
ASCENSION ISLAND WIND FARM

G. HOTCHCO

NOTE TO READER: Tables and Figure in this section were excerpted from other documents. Therefore, Table and Figure numbers and titles were left in tact.



GEORGE HOTCHCO (HOTCH-KO)
ELECTRICAL ENGINEER
6550 ABG/DERR, PATRICK AFB FL 32925



DEPARTMENT OF THE AIR FORCE
COMPREHENSIVE PLAN
LOCATION MAP
ASCENSION
B-1
NORTH ATLANTIC
OCEAN
SOUTH ATLANTIC
OCEAN
AFRICA
SOUTH AMERICA
PACIFIC OCEAN
INDIAN OCEAN
SAUDI ARABIA
RED SEA
MEDITERRANEAN SEA
CARIBBEAN SEA
USA
CAPE CANAVERAL
GRAND BAHAMA
ANTIGUA
PRETORIA
INTERNATIONAL TIME ZONES

STATEMENT OF WORK

1. BEST LOCATION
2. NUMBER OF GENERATORS
3. SIZE
4. RF INTERFERENCE
5. NOISE CONSIDERATIONS
6. MAINTENANCE PROBLEMS
7. RELIABILITY
8. EFFECTS ON BASE WATER PLANT
9. COST:
    - GENERATOR
    - SITE PREPARATION
    - ROAD
    - POWER LINE
10. ECONOMIC ANALYSIS
11. FUNDING UNDER "WIND-ENERGY SYSTEMS ACT OF 1980"

COST OF STUDY

USAF ESTIMATE	A-E PROPOSAL
$18,000	$71,000
25,000	57,000
25,000	43,000
34,000	34,000

CLIMATOLOGY FOR ASCENSION ISLAND AAFB
Prepared July 1976
Period of Record: Sept 1942 - Dec 1946, Feb - Apr 1947, Sept 1957 - Jan 1967

PARAMETER / MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL TOTAL
Wind													
Prevailing	ESE 15	ESE 15	ESE 15	ESE 17	ESE 17	ESE 17	ESE 17	ESE 16	ESE 15	ESE 15	ESE 15	ESE 15	ESE 16
Peak Wind	ESE 30	ESE 33	SE 30	ESE 32	SE 36	ESE 33	ESE 33	SSE 31	ESE 35	ESE 30	SE 30	ESE 30	SE 36
Temperatures													
Extreme Max	89	89	89	90	89	87	87	84	84	84	86	87	90
Mean Max.	83	85	86	86	84	82	81	80	79	79	80	83	82
Mean	78	80	81	81	80	78	76	75	74	75	76	77	77
Mean Min.	73	75	76	76	75	73	72	70	70	70	76	72	72
Extreme Min.	66	68	70	69	67	67	67	65	63	65	64	64	63
Relative Humidity													
Mean (%)	74	74	74	72	70	69	69	70	73	74	72	73	72
Precipitation													
Days w/Precip	16	12	14	20	15	19	17	18	21	24	22	19	217
Days w/Precip ≥ .005in	7	5	7	8	6	8	7	8	10	12	8	8	94
Monthly Max (in.)	1.41	1.36	11.60	3.94	.90	1.49	1.40	1.31	.93	.86	.78	.52	----
Monthly Mean (in.)	.33	.36	1.46	1.21	.43	.61	.50	.44	.38	.48	.29	.29	6.78
Monthly Min (in.)	.07	.01	.07	.05	.01	.05	.18	.02	.12	.10	.03	.09	----
24 Hour Max (in.)	.91	1.31	6.68	2.03	.34	.99	.82	.52	.21	.26	.17	.22	----
Thunderstorms													
Days w/Tstms	----	---	0	0	----	---	----	---	---	---	---	---	0
Fog													
Days w/Fog	---	---	0	---	---	---	---	---	0	0	---	---	0
Flying Weather													
VFR - 1000/3	743	671	743	718	742	719	743	743	716	741	719	743	8741
IFR - 1000/3 ≥ 200/½	0	0	0	1	0	0	1	1	2	2	0	0	0
GCA - 200½	0	0	0	0	0	0	0	0	0	0	0	0	0
Pressure Altitude (ft)	-290	-315	-355	-345	-265	-350	-200	-195	-215	-225	-270	-285	-274

MAC FORM OCT 67 36g GENERAL PURPOSE WORK SHEET

TABLE 2

Frequency Distribution of Wind Speed and Direction
Ascension Island Airfield(1)

From Direction	Wind Speed, KTS 1-3 (%)	4-6 (%)	7-10 (%)	11-16 (%)	17-21 (%)	22-27 (%)	28-33 (%)	34-40 (%)	%	Mean Wind Speed (kts)
N	.0	.0	.0						.0	4.7
NNE	.0	.0	.0	.0	.0				.0	7.7
NE	.0	.0	.0	.0	.0				.1	8.4
ENE	.0	.1	.1	.1	.0	.0	.0		.3	10.3
E	.1	.4	1.8	7.9	5.6	.9	.0		16.7	15.2
ESE	.1	.4	4.4	23.4	16.6	3.2	.2	.0	48.3	15.7
SE	.1	.3	3.8	14.8	9.4	2.1	.1	.0	30.7	15.3
SSE	.0	.0	.4	1.4	1.1	.3	.0		3.3	15.5
S	.0	.0	.1	.1	.1	.0	.0		.3	15.3
SSW	.0	.0	.0	.0	.0				.0	11.0
SW		.0	.0	.0	.0				.0	10.2
WSW	.0	.0							.0	3.5
W	.0	.0	.0	.0	.0				.0	9.1
WNW	.0			.0					.0	6.8
NW		.0	.0						.0	6.5
NNW	.0	.0	.0	.1	.0	.0	—	—	.2	13.2
Totals	.3	1.3	10.6	47.9	32.8	6.6	.4	.0	100.0	15.5

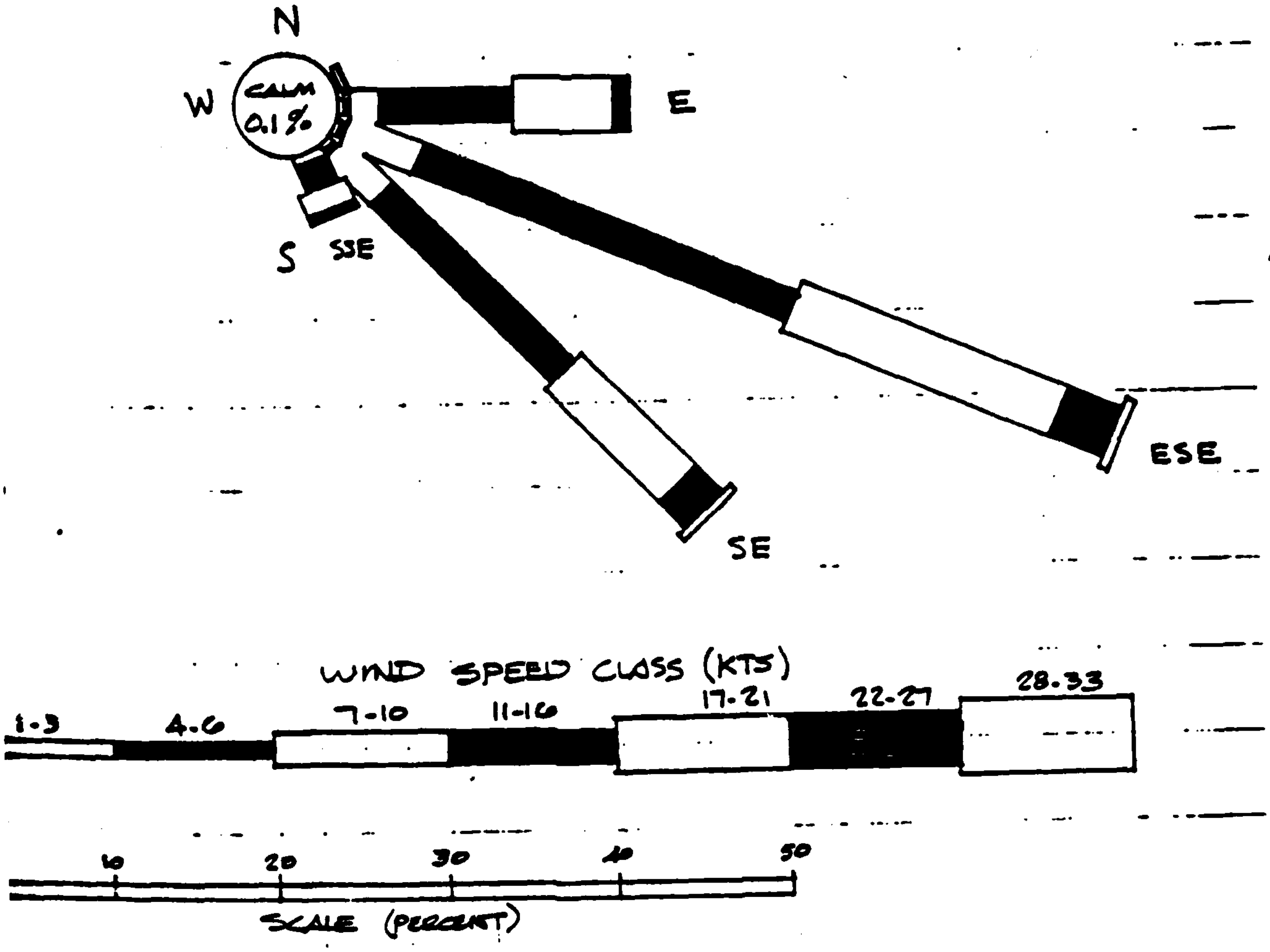
88%

99%

NOTE: Zeroes indicate values <0.05 percent.

(1) Based on 118,401 hourly observations from 1943 to 1947 and 1957 to 1967.

Source: National Climatic Center



ASCENSION ISLAND WIND ROSE

FIGURE 1

TABLE 10

20-Year Present Worth
Breakeven Costs

Wind Turbine	Annual Energy(1) (kWh)	Energy Savings(2) ($)	Wind Turbine Cost	Breakeven Cost(5) ($/kW)	
Type #1	202,524	360,716	$1.3847^{(3)}TC_1^{(4)}$	5,201	U.S. WIND POWER INC
Type #2	186,278	331,780	$1.3847^{(3)}TC_2$	4,792	ESI-54
Type #3	105,852	188,533	$1.3847^{(3)}TC_3$	2,723	DAF INDAL, LTD.
Type #4	140,786	250,754	$1.3847^{(3)}TC_4$	4,527	MERKHAM
Type #5	118,912	211,794	$1.3847^{(3)}TC_5$	6,118	JAY CARTER
Type #6	115,895	206,421	$1.3847^{(3)}TC_6$	5,963	WIND ENGINEERING

(1) See Table 8.

(2) Based on energy in previous column and energy replacement cost of 14.73¢/kWh in Year 1 escalated at 14 percent per year for the first four years and 10 percent per year thereafter.

(3) Installed Cost - 1.0000
O&M Cost - .3534
Other Cost - .0313
1.3847

(4) TC_N = Total Construction Cost for Type #N.

(5) [Energy Savings ÷ 1.3847] ÷ Rated Capacity.

CONCLUSIONS

1. MEAN-WIND SPEED OF 15.5 KNOTS (17.8 MPH) IS SUFFICIENT TO SUPPORT WTG OPERATION.

2. SITE NO. 3 IS BEST LOCATION BECAUSE OF CLOSE PROXIMITY TO POWER LINE AND ROAD.

3. PAFB SHOULD PURCHASE A JAY CARTER-25 OR ESI-54 WIND MACHINE.

4. ESTIMATED COSTS FOR JAY CARTER-25 --- $1,916/KW
   ESI-54 --- $1,987/KW

5. PAYBACK PERIODS: JAY CARTER-25 --- < 3 YRS
   ESI-54 --- < 4 YRS

6. NO CHANCE OF FUNDING UNDER WIND-ENERGY SYSTEMS ACT OF 1980.

7. HQ AFESC CONTRACTOR: "NO RFI WILL BE EXPERIENCED IF WTG'S ARE INSTALLED IN VICINITY OF POWER PLANT."

ASCENSION POWER PLANT

MINIMUM LOAD: 1600 KW

MAXIMUM LOAD: 2200 KW

ANNUAL OUTPUT: 16,380,000 KWH

JP-5 AIERCRAFT FUEL USED IN PLANT: 1,370,400 GAL
= 32,629 BARRELS

KWH/BARRELS = 502

PRESENT COST OF FUEL: 1.42 + .36 = 1.78
(36¢ "DIVERSION" COST)

COST PER KWH = 14.9¢ (FY-82)

OPTIMUM WTG CAPACITY = $\frac{1600}{4}$ = 400-KW

USE	16-20	25-KW UNITS
	8-10	50-KW UNITS
	4-5	100-KW UNITS

MEDIUM & LARGE WIND-TURBINE GENERATOR MFGRS

KAMAN - NO ANSWER

ENERGY SCIENCES, INC. - 50-KW @ 30 MPH, HORIZONTAL

WINDMASTER - 100-KW @ 30 HORIZONTAL 3-BLADE UPWIND

FLOW INDUSTRIES - 100-KW @ 32 MPH VERTICAL AXIS

ALCOA - OUT OF WINDTURBINE GENERATOR (WTG) BUSINESS

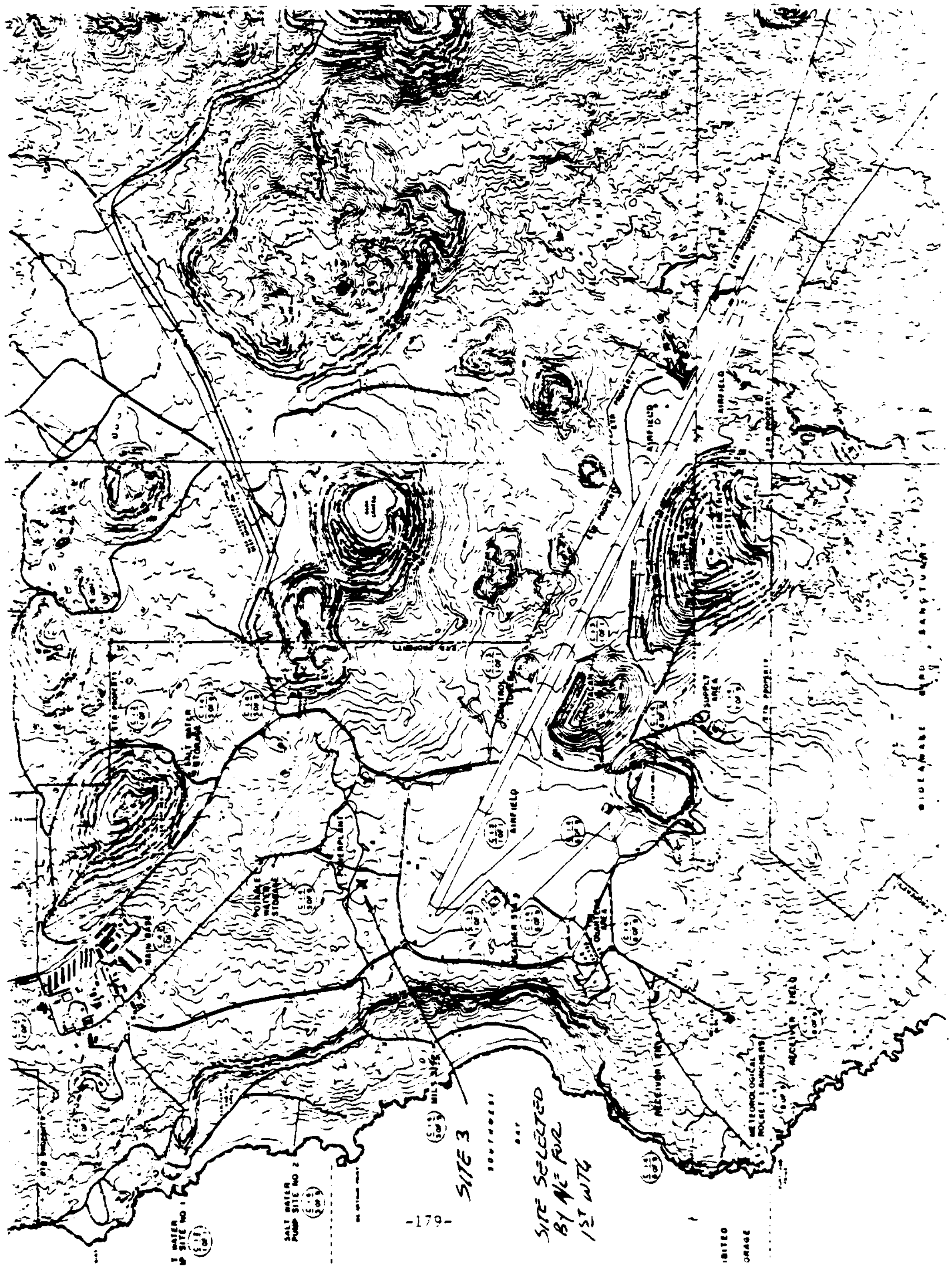
FORECAST INDUSTRIES - DEVELOPING 185-KW @ 30 VERTICAL AXIS

DAF INDAL, LTD. - 50-KW @ 40 MPH VERTICAL

UNITED TECHNOLOGY - 4-MW ONLY

MERKHAM - NOT LISTED IN TELEPHONE DIRECTORY

U.S. WIND POWER, INC. - 50-KW NOT FOR SALE


AIRFIELD
SITE 3
-179-

FUNDING FOR WIND MACHINE PROJECTS

MAJOR PHILLIP HOLDEN

ECONOMIC ANALYSIS

WIND ENERGY

Location: ______________________ Program FY: _____

Project: ____

Annual Average Wind Speed: ____________ Economic Life: ______

Date Prepared: __________________ By: ________________________

Costs:

1. Nonrecurring Initial Capital Costs:

a.	CWE (Current Year)	$__________
b.	Design (Current Year)	$__________
c.	Salvage (Current Year)	$__________
d.	Total (Current Year)	$__________
e.	Annual Inflation Factor (__%, Near Term)	__________
f.	CWE (Program Year) ($a \times e^{-}$)	$__________
g.	Design (Program Year) ($b \times e^{-}$)	$__________
h.	Salvage, (Program Year) ($c \times e^{-}$)	$__________
i.	Total (Program Year) ($f + g + h$)	$__________
j.	Investment Incentive Factor	__________
k.	Adjusted Initial Capital Cost ($i \times j$)	$__________

Benefits:

2. Recurring Non-Energy Benefits (+)/Costs (-)

a.	Annual Labor (Current Year)	$__________/YR
b.	Annual Material (Current Year)	$__________/YR
c.	Other (Current Year)	$__________/YR
d.	Total O&M ($a + b + c$)	$__________/YR
e.	O&M Inflation Factor (__%, Near Term)	__________

f. Total O&M Inflated to Prgm FY (d x e⁻) $________/YR

g. Discount Factor (@ ____%) ________

h. Discounted Recurring Costs (f x g) $________

3. Recurring Energy Benefits (+)/Costs (-): Electrical

a. Change in Annual Consumption ________/KWH

b. Current Cost per KWH $________/KWH

c. Other Charges Associated w/ WECS $________/KWH

d. Current Beneficial Cost of Energy (b + c) $________/KWH

e. Annual Cost Change (Current Year) (a x d) $________/YR

f. Inflation Factor (____%, Near Term) ________

g. Annual Cost Change (Program Year) (e x f⁻) $________/YR

h. Differential Escalation Factor (@ ___%) ________

i. Discounted Dollar Decrease (+)/Increase (-) (g x h) $________

4. Total Discounted Benefits (2h + 3i) $________

5. Discounted Benefit-to-Cost Ratio (B/C) (4 ÷ 1k) ________

6. Savings-to-Investment Ratio (SIR) (4 ÷ 1k) ________

7. Total Annual Energy Savings (11,600 BTU/KWH) ________MBTU/YR

8. Energy-to-Cost Ratio (E/C) (7÷ (1f /1000)) ________

9. Annual Dollar Savings (2f + 3g) $________/YR

10. Payback Period (1k ÷ 9) ________YRS

11. 1st Year's Energy Cost [(1i + 2g)-2f] ÷ 3a $________/KWH

NOTES

1f, g, h:	Use current ECIP guidance (ECIP Call Ltr) to determine if costs are to be ranked in the Program Year or Current Year. If Current Year, use "O" as the exponent of "e".
1g:	"0.9," if using DOE method; "1" if using pre-FY84 method.
2a:	Use 1.5% of line 1i unless a different figure can be justified.
2b:	Use 1.0% of line 1i unless a different figure can be justified.
2c:	Should include any recurring data processing costs, if applicable; e.g., correlations of wind speed to machine output.
2g:	"@ 7%" if using DOE method; "@ 10%" if using pre-FY84 method.
3a:	From nomograph or computer simulation.
3b:	Use total annual electric bill divided by total annual consumption; i.e., (average energy + demand charges)/KWH per year.
3c:	Wheeling charge per KWH, if applicable.
3h:	From latest DOE publication of differential inflation rates, normally found in the Federal Register (18 Nov 81 is latest as of 31 Aug 82) if using DOE method; "15.363" (for 20 years) if using pre-FY84 method.
5:	Applies only to pre-FY84 method. (Leave blank if using DOE method.)
6:	Applies only to DOE method. (Leave blank if using pre-FY84 method.)
11:	Break-even price for exactly amortizing construction and O&M costs over the life time of the system.

ADDITIONAL NOTES:

- Lacking other documented evidence, figure 20 year lifetime of the wind system.
- Be certain to allow for "Readiness-to-Serve" charge; application must be determined through consultation with local utility.
- Machines must be sized so that grid penetration is less than 50%. Again consult with local utility to determine penetration problems.

UNITED STATES AIR FORCE
AND
TRI-SERVICE
WIND ENERGY WORKSHOP AND CONFERENCE

UNITED STATES AIR FORCE ACADEMY

31 AUGUST - 2 SEPTEMBER 1982

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